MARKETING RESEARCH REPORT NO. 1014

PROCUREMENT PLANNING FOR THE COMMERCIAL FEED FIRM

ECONOMIC RESEARCH SERVICE • U.S. DEPARTMENT OF AGRICULTURE

ABSTRACT

Acceptance and routine use by most commercial mixed feed firms of a linear programming model to generate rations on an individual product basis has created many operational coordination problems, especially among the procurement, manufacturing, and marketing departments. The typical model used represents such a gross oversimplification of the total feed manufacturing system that it can be extremely misleading when used by management to plan and control operations. The primary objective of this study was to construct and test a computerized operational control system for the typical commercial feed firm. This system,which utilizes an expanded linear programming model, simultaneously evaluates procurements, production, and sales constraints in generating decision guides to be used for optimizing operational planning and control by management.

Keywords: Marketing, Transportation, Feed, Processing, Costs, Market, Structure, Management, Location Theory, and Manufacturing.

PREFACE

This study is part of a broad program of economic research conducted by the U.S. Department of Agriculture and directed toward increasing efficiency in the mixed feed industry. Results of the research program should ultimately benefit the nation's farmers, who have an interest in an efficient industry because they sell feed ingredients to the industry and, in turn, buy the finished products.

The present study is the third phase of a specific research program for developing techniques for improved management decision-making. The primary objective of this phase was to develop a computerized operational control system for simultaneously evaluating ingredient procurement and production and sales of feed to generate optimum management-decision guides. The two prior phases dealt with the optimization of inventories, both ingredient and finished product, and plant location.

William A. Faught and Carl J. Vosloh, Jr., made valuable contributions throughout this research program. The authors express thanks and appreciation to the industry cooperator who provided the data necessary to test and evaluate the system.

Washington, D.C. 20250 November 197[illegible]

CONTENTS

TEXT TABLES

APPENDIX TABLES

TEXT ILLUSTRATIONS

Figure		Page

APPENDIX ILLUSTRATIONS

SUMMARY

A commercial mixed feed firm tested the computerized, operational control system (OCS) developed in this study and saved at least 84 cents per ton in costs in comparison with the use of its individual-product formulation model. Both models use linear programming (LP), but the OCS simultaneously evaluates procurement, production, and sales constraints in generating optimum product formulation plans.

The cooperating firm implemented the model OCS in less than 2 years, and the savings result is based on a period of full use for 6 months. Savings according to functional areas were as follows:

1. Reduced ration cost $0.42/ton
2. Reduced labor, freight, and demurrage expense ...... .13/ton
3. Reduced distribution expense and improved product pricing. .29/ton

Total ....$ .84/ton

Based on these results, LP analysis--routinely accepted as important in generating optimum rations on an individual-product basis--clearly offers a much greater benefit when employed in the OCS concept. By evaluating simultaneously the whole complex of alternatives and their interaction in procurement, multiproduct formulation, manufacturing, and sales, the system generates optimum operational plans that give management a firm basis for decisionmaking.

In contrast, use of LP analysis for individual-product formulation has actually created increased operational coordination problems, especially among the procurement, manufacturing, and marketing functions of commercial mixed-feed firms. Coordination of these functions has become more critical to the feed manufacturers in recent years, for there have been drastic changes in feedstuff price-use relationships in both the short and long run due to the use of linear programming to produce least-cost rations. The individual-product LP analysis, however, represents a gross oversimplification of the total feed manufacturing system and thus can be misleading when used as a basis for planning and controlling operations.

The OCS model developed in this study meets the following objectives: It is responsive to the dynamic aspects of feed marketing, especially those related to the procurement of feedstuffs; it is practical for all firms in the industry, regardless of size, to adopt and use; and it can utilize the existing data base as input.

Before the model OCS was tested by the cooperating firm, the researchers tested it empirically to compare the relative efficiency of the system with an individual-product LP formulation model. The OCS generated rations cost an average of 79 cents per ton less than those generated using the comparison model.

PROCUREMENT PLANNING FOR THE COMMERCIAL FEED FIRM

by

Thomas L. Guthrie and James C. Snyder 1/

INTRODUCTION

Linear programming (LP) is being used by most commercial feed firms to formulate economically competitive rations. The typical LP analysis evaluates only costs of alternative feedstuffs, and rations are generated one at a time. Generally, the larger firms in the industry have pioneered in the introduction, acceptance, and routine use of LP analysis. Other firms have lagged in direct relation to their relative size.

The acceptance and routine use of LP analysis has created for many firms operational coordination problems, especially among the procurement, manufacturing, and marketing functions. Coordination of these functions has become more critical to the feed manufacturers in recent years, for there have been drastic changes in feedstuff price-use relationships in both the short and long run due to the use of linear programming to produce least-cost rations.

This report shows that LP analysis need not be limited to the formulation of rations on an individual basis, but rather that it may be used to solve the operational coordination problems while simultaneously providing information for determining the most efficient rations for all products. Discussed in detail is the use of an expanded LP-based analysis which generated optimum feedstuff procurement, production, sales, labor, and equipment plans for future periods of operation. This more comprehensive LP model can be used effectively by many firms in the industry, regardless of size, with a minimum of organizational changes and addition of personnel. With the use of an LP-matrix compaction technique, the cost of input data preparation and computer processing is modest both in absolute terms and in comparison with potential gains.

Problem

To an ever increasing degree, top management of commercial feed firms is being pushed further away from the actual job of managing the firms. The major forces have been the:

(1) Continuing increase in tonnages produced per firm due to growth of the industry and to continued mergers and acquisitions within the industry

---

1/ Thomas L. Guthrie is an assistant professor at Indiana University, Fort Wayne, Ind. When this study was conducted, he was an agricultural economist, Marketing Economics Division, Economic Research Service, stationed at Purdue University. James Snyder is professor of agricultural economics, Purdue University, Lafayette, Ind.

(2) Geographical decentralization of operations via satellite mills and district warehouses

(3) Development of multiple product lines, resulting from rapidly expanding nutritional knowledge, and increasing specialization of farmers and feeders

(4) Continual push for a differentiated product brought about by the highly competitive environment in which most feed firms find themselves.

The typical manager finds increasingly that he is being removed from a firsthand and intimate knowledge of routine business operations and therefore is remote from the information needed to exert positive influence over the diverse operations of the firm. To overcome this information deficiency, he has typically surrounded himself with staff personnel and added more layers of management. This approach may be moderately successful, but more often than not, the end result has been to remove top management even further from the operational problems --even to the point that they may not hear about the problems until it is too late to act.

Since routine operational decisions concerning procurement, manufacturing, and sales activities are being made continuously in any viable feed firm, who or what has occupied the vacuum left by top management? Typically, the answer is planning guides developed using extensions of output from rather naive mathematical programming models. As noted earlier, some type of LP analysis is being used by practically all feed firms because initial use of it proved to be so commercially beneficial. The essential problem is that the LP model used by most firms represents a gross oversimplification of the total feed manufacturing system and thus can be misleading when used to generate operational plans. Compounding the problem is the fact that the personnel responsible for such analyses often lack top management perspective that is essential for overall company profitability.

Assuming the above discussion is relevant to the typical use of LP by commercial feed firms today, then from the standpoint of top management, the procurement, manufacturing, and sales departments are "out of control." The primary objective of this study was to build and test a computerized operational control system (OCS) for commercial feed firms which will yield better planning perspectives and more informed decisionmaking by top management, leading to a stronger profit position for the firm which incorporates the system.

History

Using the simplex method developed by Dantzig and Laderman (3) 2/ in 1947, Waugh (14), in 1951, made the first practical application of LP to a feed formulation problem in his classic article "The Minimum-Cost Dairy Feed." The implications have been monumental in that some form of LP and related activity analysis technique is being used by practically all commercial feed firms to solve the feed formulation problem and by the agricultural sector in general to solve its diverse blend-type problems.

2/ Underscored numbers in parentheses refer to items in Literature Cited at the end of this report.

Waugh assumed that the supply of all feedstuffs considered as possibilities for a ration was perfectly elastic. However, in practice, the production of commercial feeds using optimum-cost rations often requires more of a feedstuff in some of the rations of a multiproduct line than is available or can be obtained. The supply patterns for some feedstuffs are highly institutionalized, so that supplies must be contracted far in advance of delivery. Depending on geographical location in relation to the source of certain feedstuffs, commercial feed manufacturers receive feedstuffs at varying delivery times which influence available supply. Conversely, as a matter of policy, some firms maintain minimum-market positions in certain feedstuffs regardless of whether the feedstuffs are required in any optimum-cost rations.

Once this was recognized, it became apparent that the use of LP for individual ration formulation is an incomplete specification of the problem as far as commercial feed manufacturers are concerned. Feedstuff supply constraints, applicable not only to all feeds of a line but also to all mills of a manufacturer, needed to be added to Waugh's model where appropriate (12).

Since the realization of the limitations of Waugh's model, there have been several approaches to solving the problem, when optimum-cost rations are being used, of allocating a feedstuff(s) among rations (and mills) when the supply of feedstuff(s) is limited or in excess of that amount needed for the manufacturing period (7). One of the first approaches to solving this problem was to arbitrarily assign "by hand" the amounts of each supply-constrained feedstuff to be used in each ration. Of course, the assignments were judgmental and thus lacked any normative character.

Shadow-Price Adjustment

Users of LP analysis quickly recognized that for an allocation of a constrained feedstuff among rations to be optimum, the shadow price(s) for the associated row(s) in all rations must be equal. This criterion is optimum, but the unnecessarily restrictive assumption is made that there is no interaction among rations; that is, rations do not change in response to a constrained feedstuff situation. Also, to readjust "by hand" among all rations in a commercial situation is for all practical purposes ridiculously difficult and expensive.

Block-Diagonal Model

More recently, firm models have been proposed that consider simultaneously not only the optimum-cost rations for all products of a manufacturer given feedstuff supply constraints but, also, other constraints such as production, labor, storage, handling, and capital.3/ In this type of comprehensive model, all constraints are considered in determining simultaneously the optimum-cost rations for the full line of products. In the case of feedstuffs, the truly optimum allocation among alternative uses is determined.

For most feed manufacturing operations, the block-diagonal model contains a large number of rows. Each product occupies a block in

3/ For a detailed explanation of the handling of these other types of constraints, see Snyder, Nelson, and Guthrie (10), pp. 115 and 144.

the model with a number of rows equal to the number of product specifications, and all the blocks form a lengthy diagonal when the model is structured in row and column format. To appreciate the number of rows involved, assume a commercial firm is manufacturing 60 different products. If there is an average of 20 nutrient and feedstuff specifications per product, then 1,200 (60 x 20) specifications (or rows) are needed just to express the characteristics of the 60 products to be manufactured. Until the recent advent of third-generation computing hardware with its associated LP software, this size problem could be accommodated on only a few of the largest computers in existence unless decomposition techniques were utilized. From a practical standpoint, assuming a computer can accomodate the problem, the cost of obtaining an optimum solution to a problem of this size may exceed any resultant savings.

Operational Control System

As noted before, the primary concern in this study was to build an OCS for planning and controlling the routine operations of a commercial feed manufacturing firm. "Operations", as used here, is exclusive of actual manufacturing scheduling. The control function embraces all those activities by which a firm's operations are guided and motivated to the attainment of a desirable end. Control begins with the determination of objectives through the medium of such activities as profit goals, work programs, procedures, and quality standards. The determination of objectives results in a plan which is used in guiding the system. An individual working within the system (for example, at the subsystem level) can better accomplish the task at hand and gain satisfaction knowing that his performance complements the total system if he is able to meet the objective in his plan.

Finally, control includes the appraisal of a system's performance by those responsible for its optimum performance. True control is established only when differences between planned and actual performance are analyzed and when management has established effective measures to avoid suboptimum performance in all controllable parts of subsystems.

For the commercial feed firm in particular, specific objectives of any control system would include optimum-cost rations, minimum demurrage, and low manufacturing costs for a given level of production. These all contribute to maximum profit in the short run. If the control system can generate ration recommendations, procurement plans, and other plans that are optimum from an overall standpoint, top management can introduce the plans with full awareness that if each plan is executed, maximum profit will be achieved. In addition, management can compare actual results with the plans and determine whether discrepancies were justified because of exogenous conditions which changed after the plans were generated or whether corrective action is necessary.

Variable Identification

To develop a plan from a firm's stated objective of increasing profits, one must identify and control the pertinent variable(s) existing within the system. As a first approach to this problem, Snyder and Swackhammer (11) separated controllable from uncontrollable

(shortrun) variables. Figure 1 illustrates a delineation of eight controllable variables which are closely related to profit performance for the typical commercial feed manufacturer. Throughout the industry there is significant variation from figure 1, depending on such characteristics as firm size, product policy, and particular competitive atmosphere; however, the list presented is accurate for most firms in the industry.

When the firm is viewed as a system, the extent of the interdependence and complexity among variables becomes obvious. For example, decisions concerning optimum-cost rations cannot be made without considering feedstuff availability, product specifications, and product mix. Feedstuff procurement must be related to product mix, rations used, and product demand. In turn, product mix is closely related to pricing and promotion policies and to labor and equipment capacity. The use of working capital in the various production and sales activities must be analyzed in the light of competing product and sales alternatives. Thus, it becomes clear that contribution to profit and overhead is ultimately influenced by decisions made for each of the eight controllable variables. A large number of decision alternatives exist within the total system and there is only a remote possibility of ever choosing (or even generating) the optimum alternative without major assistance.

Once the variables to be controlled have been recognized, the problem becomes "how"? What is needed is a total system which can interpret the interactions of all the variables and then determine a maximum-profit set of decisions, given one set of parameters for the uncontrollable variables.

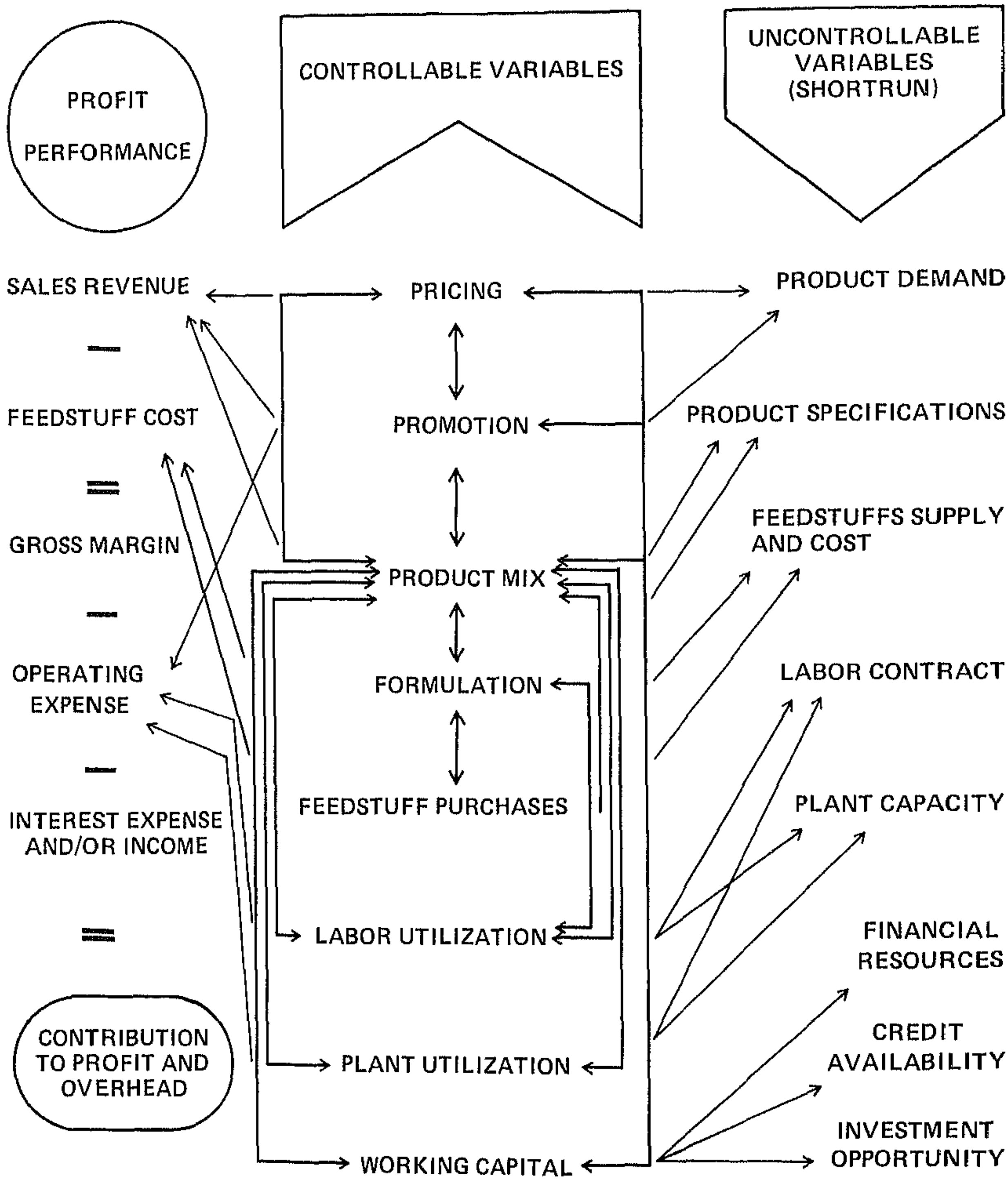
Linearity Assumption

If the actions and interactions of the controllable decision variables are linear (or stepwise linear), they can be theoretically structured as an LP model, and the model can be maximized. In general, the effects of variables in the commercial feed manufacturing situation are linear in nature. For example, the combination of X_a amount of feedstuff A and X_b amount of feedstuff B results in $X\ (a + b)/d$ amount of product (where d is some linear adjustment for shrinkage); the combination of X_c amounts of labor, X_d amounts of plant facilities, and X_e amounts of working capital results in $X\ (c + d + e)/f$ amounts of production (where f is some linear production factor). An accepted theory holds that production is curvilinear as capacity is approached; however, the validity of the use of an LP model is not impaired if the production curve can be adequately represented by different linear approximations; that is, stepwise linearity.

Potential Nonlinearity Problem

Another variable which was not considered is the growth response of animals to different nutrient levels. Nutritionists have generally experienced curvilinear response curves when studying the effect of feeding animals at varying nutrient levels. They are interested in only one point on the curve--the nutrient level that yields maximum performance. However, when considering the animal rather than the ration as the end product, there may be some other level of any

VARIABLE CONSTRAINTS AND PROFIT PERFORMANCE IN A COMMERCIAL FEED FIRM



Reprinted from (10).

Figure 1

particular nutrient (or nutrient combinations) which will actually result in greater total profit because of the reduced cost of the ration containing the more economically desirable nutrient levels. Presently, this is no major problem in the commercial feed industry because feed, not the animal to which it is fed, is considered as an end product. However, fully integrated operations may consider the animal as an end product and thus reap the benefits from these economically superior rations. In the foreseeable future, the comparative advantage enjoyed by fully integrated operations may compel the commercial feed manufacturer to invent new types of sales contracts so that both he and his customer can share in the added profit from this type of feeding program. At that time, any OCS being used would have to have major modifications to accommodate curvilinear growth curves. 4/

Systems Design

Having stated the objective and the operationalized variables which may be used in obtaining it, the next step is to design the system; that is, components must be arranged in some combination to help meet the objective. One way to design the system is to view the typical feed firm operation as a flow process, analyzing each segment and investigating the relationships and contributions of the parts to the whole (8). Snyder et al. (10) have done this on a macrobasis for the feed industry. Their results are shown in figure 2.

Sales forecast. The system flow begins with a forecast of product sales. This is the logical place to start for two reasons:

(1) In the short run (uncontrollable variable), product demand is given. Any impact on sales resulting from special promotion, pricing change, or other marketing tactics has little potential effect on product demand because sufficient time has not elapsed for the effect to be felt.

(2) It is assumed that the feed firm has a policy of attempting to complete all potential sales; therefore, in the short run, all procurement, manufacturing, and transportation efforts will be directed toward this end.

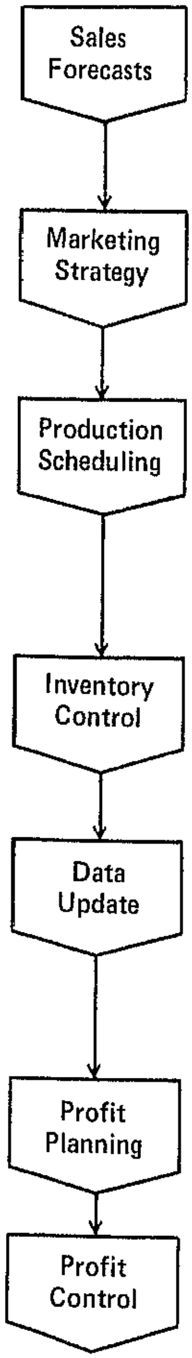
Thus, the main role of the sales-forecast subsystem in the short run is to provide a guide that the sales manager, sales supervisors, and the manufacturing-sales coordinators can use in planning shortrun operations. Individuals in manufacturing can be provided with specific and accurate guides indicating what manufacturing needs will be in the short run.

Marketing strategy and production scheduling. The marketing-strategy and production-scheduling subsystems are optional modules of the complete OCS but will not be a part of the system presented herein. This is not to imply that marketing and production scheduling are not important factors in the operation of a successful commercial feed firm.5/ In fact, the marketing function in agribusiness firms in

4/ For futher discussion of this issue, see Dudley and Parks (4).

5/ For an excellent example of a marketing system applicable to an OCS as a subsystem, see Funk (5).

OPERATIONAL CONTROL SYSTEM COMPONENTS FOR A TYPICAL COMMERCIAL FEED FIRM



Use of the OCS is initiated with computer forecasts of product sales. These computer forecasts are reviewed by management prior to their further use in the OCS.

Use of the marketing-strategy simulator provides a scientific method of analyzing the impact on sales of special promotions, competitive pricing, or any other aspect of an overall marketing plan.

The production-scheduling simulator evaluates the feasibility of manufacturing the projected feed sales. It is also used to schedule the sequence in which feed products should be manufactured.

The inventory-control simulator is used to establish minimum-safety stock levels of feedstuffs used in manufacturing. This helps avoid costly stockouts.

All current cost, nutritional, and other technical data must be updated to reflect current conditions. An effective data-generation system is needed to ensure the timeliness and accuracy of data inputs.

Given the above data generation and analysis, the OCS is used for developing profit-planning reports.

For profit-control purposes, the OCS is used to generate comparisons of actual versus planned performance in each planning area. Variance is computed in terms of price, volume, and mix components.

Reprinted from (10).

Figure 2

general is becoming one of the critical factors in determining success or failure. Hastily planned and ill-executed marketing programs put a firm in a weak competitive position in the industry. However, the time frame of reference for this study is the short run, and efforts to change the marketing mix in a major way usually cannot be made effectively at the last moment. At a minimum, several weeks' lead time is required for even short-term market planning. Longer term planning typically involves lead times of several months or years. As for production scheduling, 6/ major benefits can accrue as a result of a systematic analysis of this function. These benefits include:

(1) Improvement in customer service

(2) Reduction of labor cost

(3) Increased efficiency in machine utilization

(4) A more orderly production pattern.

Production subsystems of differing levels of sophistication may be added at any time to the OCS in a modular fashion. If an OCS is developed without the production-scheduling module, the only relevant question to be asked concerning production (from the standpoint of the OCS) is whether manufacturing can meet any particular forecasted sales. If the answer is no, production priorities must be ordered until production desires can be reconciled with capacity constraints. These capacity constraints can be expressed as constraints in the LP model, so, to this extent, manufacturing feasibility *per se* can be tested in the OCS without the use of the production-scheduling module.

Inventory control. System optimality must be maintained, not only within a particular time period, but also over successive periods. If the time periods are interdependent, as they surely are in the commercial feed industry, this interdependence must be accounted for in the OCS. By use of an inventory-control subsystem, this dynamic aspect can be introduced into what otherwise would be a static OCS. Stafford and Snyder (12) lucidly summarize the problem:

> The flow (of feedstuffs) is affected by the solution to static models (for example, a LP model). However, if the solutions to the static models are to be "fully optimum" production plans, the models must include an evaluation of the effect of current activities on all future production possibilities. Since future production possibilities are limited by future flows, it follows that current production planning models must include evaluation of probable future (feedstuff) flows. In other words "fully optimum" solutions are affected by the flows as well as the flows being affected by the solutions.

This two-way relationship between stochastic flows and the solution to a static model may be handled in the OCS utilizing an inventory-policy evaluation subsystem.

6/ For a recent discussion of the theory of production scheduling, see Conway, Maxwell, and Miller (2).

Data update. The data-update subsystem performs a data collection and ordering task in preparation for making an optimum profit-planning calculation. Output from the subsystems described above plus uncontrollable-variables data are assembled, sorted, ordered, and prepared in an input format acceptable to the LP model.

Profit planning. The profit-planning subsystem contained in the OCS is a mathematical description of the planning phase of the control system for the commercial feed firm. When solved, this LP subsystem can be used to generate optimum planning guides for the firm.

Profit control. Finally, a profit-control subsystem which utilizes a systematic cost-accounting comparison routine is used to compare actual versus planned performance. Output from this subsystem provides feedback to top management who are in a position to analyze the variations and determine corrective action where appropriate.

System and Information Flow

It is necessary to construct an information flow system as a portion of any total system. When constructing it, the objective is to identify the vital decision areas within the system and then coordinate the flow of information with them. The vital decision areas of interest in the OCS are procurement, production, and sales. Figure 3 is the proposed information flow system for coordinating these activities in a typical commercial feed firm.

Production planning. Entering the system in figure 3, one notes uncontrollable-variable input data consisting of daily sales orders [1], feedstuff prices, commitments, and availabilities [2], and daily feedstuff receipts [3]. These data on the inventory of feedstuffs available for production are utilized by the OCS [5] to calculate the optimum plan for the daily 7/production run. The plan is summarized as production and formulation reports [6] which are used in making the daily production run [7]. After completing the production run, the feedstuff inventory is reexamined [8], and any production not completed is reported[9]. The produced feed flows out of the system as sales [10].

Procurement planning. Given a sales forecast report [13] derived from a sales forecast model [12] which uses a history of daily sales data [11] and given feedstuff prices, commitments, and availabilities [2] for a future production period of interest, one can calculate the optimum plan for the period using the OCS[14]. By combining the forecast of feedstuffs volume needed for the period [15] with the minimum inventory needed[16], one can calculate an ordering schedule of feedstuff requirements [17]. Finally, a history of service time and running inventories by feedstuff[18] is used as input to an inventory-control model [19]. The feedstuff-flows problem is evaluated in the model in such a manner as to minimize the total cost of stockouts plus inventories.

It is, of course, necessary to integrate the information reports with either an existing or redesigned organizational structure to

7/ The term "daily" may mean just that, or it may be interpreted as semidaily, weekly, or any other interval, depending on the feasibility and administrative practicality of reformulating for production purposes. For a discussion of reformulation frequency, see Hayes (6).

OCS FLOW CHART FOR A COMMERCIAL FEED FIRM

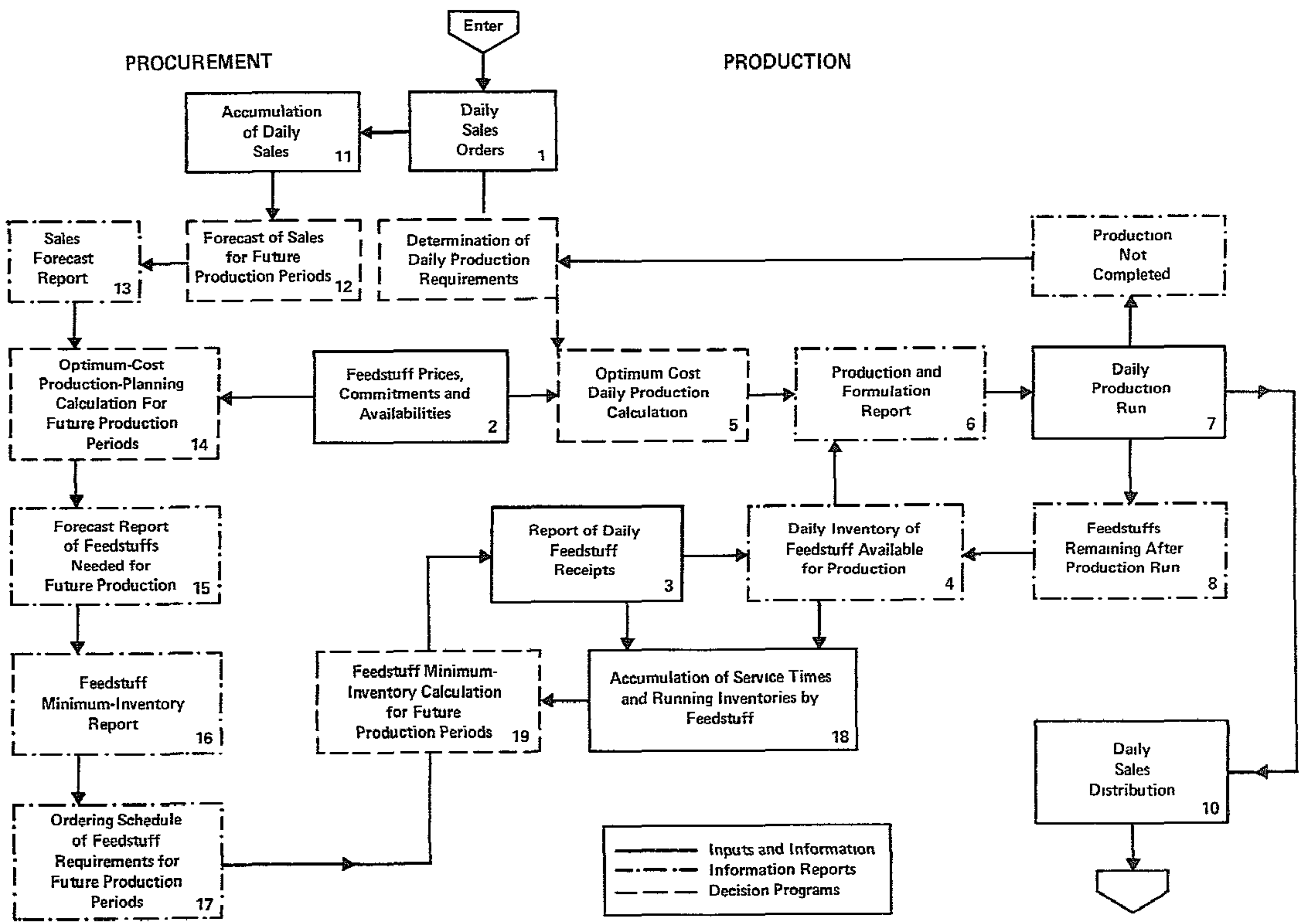


Figure 3

obtain proper feedback for control purposes at the vital decision points. The resulting integration is likely to vary extensively owing to the diverse organizational structures that exist among commercial feed firms.

Since hedging is such an integral part of procurement activities in most commercial feed firms, a natural question arises as to how use of the OCS can facilitate buying and selling decisions when a firm is hedging. If procurement personnel have concluded that the futures prices (representing different delivery months) for a feedstuff(s) are a "good" buy, or if sales personnel have just contracted future product sales, then hedging is desirable, assuming the job of procurement is to match feedstuff procurement with sales (contracted or otherwise) at the lowest total cost. Having decided to hedge, the hedger must know what volume of each feedstuff to hedge. Projected product sales for the different periods of interest plus futures prices for feedstuffs for the same period may be input to the OCS. Output from the OCS is the optimum combination of feedstuff volumes needed to meet projected sales at least cost. Ancillary information as to the cost of each product produced is also obtained by using the OCS. This cost, based on the use of futures prices, may be used in determining quoted prices for contracted feeds, since futures prices are generally used in this activity whether or not hedging is practiced.

More importantly, the OCS may be used subsequently to determine timing of the feedstuff contract(s), which offsets the futures contract(s). If feedstuffs for contracted products have been hedged, losses from violent market swings have been eliminated (except for basis losses); however, the potential for improving the gross profit margin on the products has not been eliminated. Assuming that the price relationships among feedstuffs are continually changing, occasionally, it should be possible to make offsetting feedstuff contracts. The contracts can be either for subsequent delivery of the same feedstuff or futures in a different commodity which may be substituted in the feed mix to produce the originally contracted product more economically. In making offsetting contracts, the only problem is in having the ability to interpret changes in the price relationships among feedstuffs. This is no problem, however, if an OCS is available. Given existing feedstuff contracts, the prices of other available feedstuffs for a period of interest, and the administrative and commission costs involved with changing contractual positions, the OCS may be used readily to determine superior contractual combinations, if in fact they exist. The fundamental factor within the procurement department is then reduced to timing. If, for example, the OCS has detected a favorable movement in a price spread between two feedstuffs, the question is whether the spread will become even more desirable or whether now is the time to "lock in" the superior position. Unfortunately, the OCS does not answer this question, but when the procurer does decide to take advantage of a change in a price spread, the OCS is able to determine the extent of a substitution in terms of quantity. Heretofore, the answer was determined by using subjective methods such as "judgment" and "experience"

SALES-FORECASTING SUBSYSTEM

The primary function of the forecasting subsystem is to generate acceptable sales-forecast input data for the OCS. The importance of

"good" sales forecasts is obvious in business planning. Manufactured volumes and master production schedules can be more accurately established from accurate sales forecasts. Direction can be given to establishing an inventory policy and procurement plan that balances manufacturing and inventory levels to avoid excessive holding and/or lost-sales costs. Labor and equipment needs can be resolved using the forecasts, thus permitting more accurate estimates of requirements in these areas. In commercial feed firms manufacturing multiple products, valuable insights can be provided concerning the character of the product mix. The mix is extremely valuable when determining future pricing and promotional strategies since an undesirable mix from a manufacturing or profit margin standpoint may be altered through the use of different strategies. In the longer run, forecasts can aid in the evaluation of plant capacity and financial needs.

The fact that future sales are uncertain and thus not capable of being forecast should no longer be acceptable to the executive. In the longer run, even simple averages of past sales have generally proven superior to guesses. Often hidden among the seemingly random fluctuations of sales are trends, seasonal factors, and longrun or shortrun cycles. Decomposition of this time-series data to identify these individual components has proven to be rewarding. Numerous approaches to forecasting have been developed (1), and a multiple-factor exponential-smoothing model has proven especially desirable in an agribusiness application having many characteristics of sales similar to those of commercial feed manufacturing.8/

Computer Orientation

The assumption is made that a computer-oriented forecast model will be the prime generator of forecasts. Computerized forecasts may not always be more accurate than human predictions; however, they can be obtained so much faster and so much more cheaply that sacrificing some accuracy if necessary may be advantageous. More frequently, the computerized forecasts are significantly more accurate than the human predictions.

Forecast Data

Source

In determining data sources, the prime problems are availability and applicability: What data are available for use in forecasting the variable of interest, and which data bear the most relationship to it?

The cooperating firm in this study used retail-sales data to forecast production needs. This type of data is readily available from accounting records. Data applicability is predicated on the assumption that (1) finished-product inventory is negligible and/or (2) there is a constant flow of finished product to and from inventory.

8/ For a detailed evaluation of the forecasting model used in the OCS, see ch. II of Swackhamer (13).

Sampling Interval

The sampling interval is the time that elapses between an observation of the variable of interest at time t and another observation at time t + 1. Cost primarily determines the optimum-sampling interval. There is a decreasing cost associated with more infrequent taking of observations and calculating of a forecast, but there is a simultaneously increasing cost associated with the increasing insensitivity of the forecast model to discern change. The optimum-sampling interval is sufficiently long so that the forecast can be interpreted by management, and administrative action can be taken before the next observation in the series.

Little work has been done to determine the true shape of the forecasting-cost curve for commercial feed manufacturers. However, one can make some inductions as to the relative shape of the curve. First, primarily for accounting reasons, most data of interest for forecasting are summarized weekly. One would hypothesize that the additional administrative cost of producing semiweekly or even daily summaries would be quite high in comparison with the weekly accounting summaries. Second, the sampling interval should be sufficiently small to interpret shortrun changes in sales caused by changes in such variables as the weather, holidays, animal marketings, and planting and harvesting pressures. A 2-week or longer sampling interval is just not sufficiently short to interpret the changes caused by these types of phenomena. Thus, by process of elimination, a 1-week sampling interval for sales data is a good choice.

Characteristics

One of the easiest ways to become thoroughly familiar with the characteristics of the data is to plot them. In doing this, the plotter inevitably starts to forecast the next point on the graph, which results in at least a cursory analysis of the characteristics of the data. This can give a much better appreciation for the type of forecasting model that may be most appropriate. The cooperating firm in this study manufactures a complete line of products having obvious differences in characteristics, so it was necessary to plot a sufficient number of products to discern these differences.

The Model

Having become familiar with the sales-forecasting subsystem in general and the data in particular, the manager can establish some criteria to be used in choosing an appropriate forecast model. First, it must be sufficiently accurate in forecasting to allow management to make desirable decisions. Second, it must be capable of generating multiple-product forecasts without unreasonable computational expense or time requirements. Third, input-data requirements should be simple, preferably to the point of using existing data.

The aforementioned multiple-factor exponential-smoothing model meets all of the above criteria for a good nonpredictive-type forecast model. The only input to this forecasting model is the past history of sales of the product to be forecast, and not, for example, such information as current activities in the market, the industry, and

the economy; sales of competing and complimentary products; price changes; and advertising campaigns. The model can be expressed as a computer program which is economical and simple to process.9/

Forecasting Selected Products

Before the model can become useful for forecasting purposes, certain parameter values must be assigned. Possible sets of A (smoothing), B(seasonality), and C(trend) coefficients must be chosen. A question arises as to the values that the coefficients will be assigned and to the number of sets of coefficients to be evaluated. The only a priori limitation on the values is the following: 0 $\leq$ smoothing coefficient $\leq$ 1. However, from a practical standpoint, this range can be narrowed. If A = 0.3, the five most recent observations get weights as shown in table 1. A plot of the weights assigned to observations yields the exponential curve from which the technique derives its name--exponential smoothing. If other smoothing coefficients were evaluated as above, the influence that the choice of A has on the weighting of older observations versus more recent ones would become clear. The smaller the smoothing coefficient, the more heavily older observations are weighted and conversely. Since it is wise to distrust any sample in commercial applications consisting of only three or four observations, the practical upper limit for the smoothing coefficient is approximately 0.3.

As for the number of sets of coefficients to be evaluated, the question is entirely one of economics --the cost of evaluating more sets versus the cost of loss of accuracy in forecasts due to the selection of a less than optimum set because of an insufficient number being evaluated. The computer program of the forecasting model is quite efficient, so certainly all possible combinations of coefficients that may conceivably be chosen in a forecasting situation should be evaluated. Thirty sets of coefficients were used in this study. 10/

Table 1 --Assigned weights using an exponential-smoothing coefficient of 0.3

Observation period	Weight
Current observation	0.3
Observation 1-period old	0.21
Observation 2-periods old	0.147
Observation 3-periods old	0.103
Observation 4-periods old	0.072
Total	0.832

9/ For a derivation of the multiple-factor exponential-smoothing model, see Winters (15).

10/ Loaded on the Purdue University CDC 6500 computer (MACE operating system, September 1969), the program evaluates 30 sets of coefficients and 144 observations in approximately 15 seconds, or one-half second per coefficient set evaluated.

Next, there is a question as to what portion of the data shall be used in calculating the test statistic which is used in determining the optimum set of smoothing coefficients. If calculation of the test statistic is limited to the evaluation of the last of three or four observations, a set of coefficients may be chosen which does a very poor job of forecasting in the longer run. Consider the series of sales in figure 4. If one attempted to forecast sales for week 37, having just completed week 36, and calculated the test statistic over only the four most recent observations, a set of smoothing coefficients that discerned the periodic increase in sales over the four periods would be chosen. However, the use of this trend coefficient to forecast sales in week 38 would give a misleading forecast. It would indicate that there was an increasing trend in sales when really there was just a shortrun aberration. The test statistic should be calculated over a sufficient period of observations to negate the characteristics that are not really present. On the other hand, one is interested in forecasting correctly today, not in how well a set of smoothing coefficients forecast an observation that occurred 2 years ago. Observations this old are of use only in forming a historical base. Determining the observations over which the test statistic is to be calculated is a judgmental decision and to a certain extent depends upon the characteristics of the data. A 6-month period was used for evaluation purposes in this study.

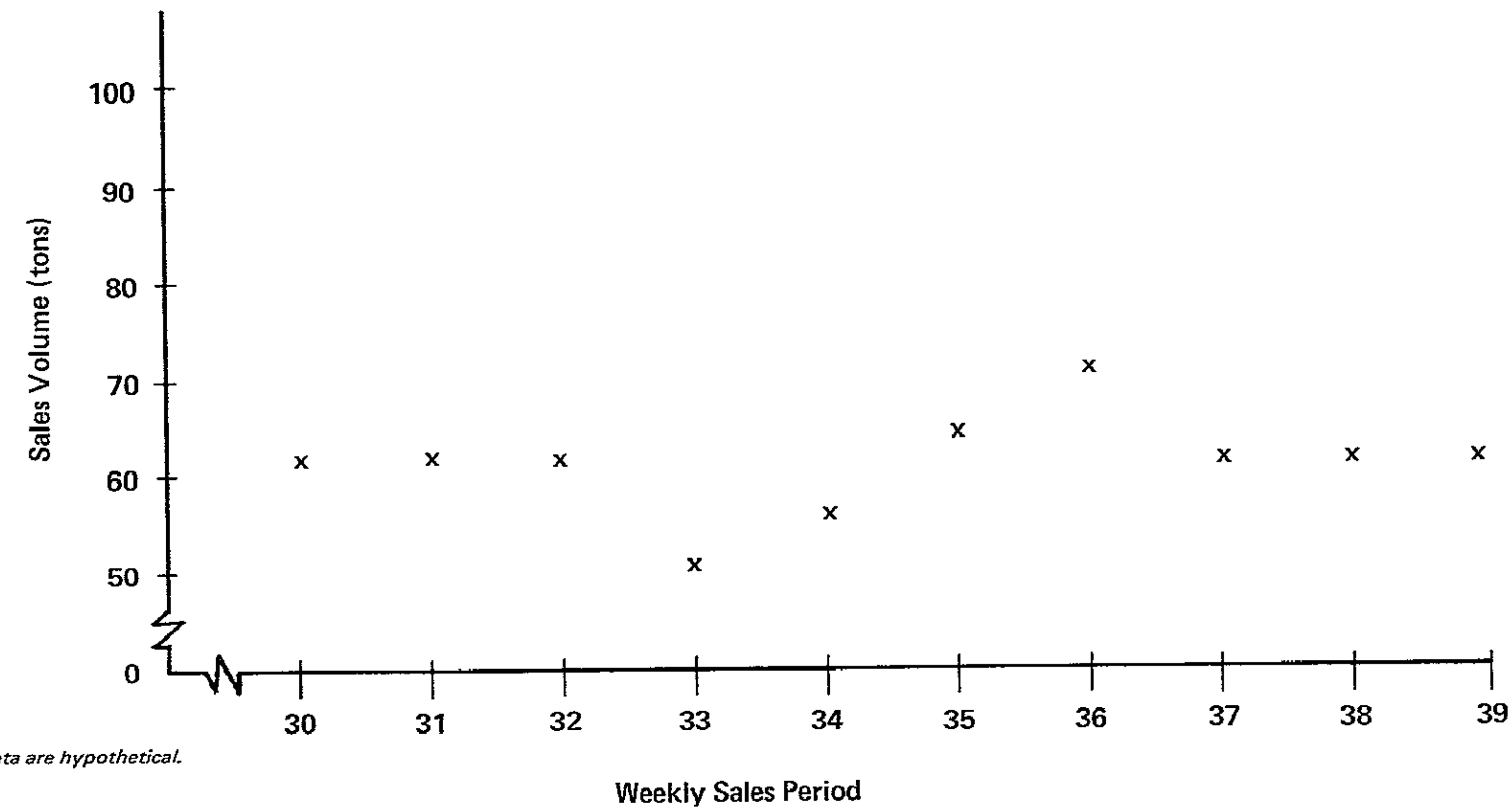
Finally, for reasons to be presented later, it was deemed desirable to make weekly forecasts for each product. Sales of any product are forecast for 4 different weeks. It is desirable that each of the four forecasts be "good", but it is preferred that any error be more likely to occur in the fourth week forecast rather than the first week forecast. The forecast program is designed to allow this possibility. The program can make forecasts any number of periods into the future, and the test statistic can be calculated as a weighted average of the errors for each of the desired number of periods. For example, if one desires to have individual forecasts for each of 4 weeks into the future, the first week forecast error can be given a weighting of 0.4, the second week a weighting of 0.3, the third week a weighting of 0.2, and the fourth week a weighting of 0.1. In the case of forecasts made in this study, this was the weighting process used for calculating the test statistic.

Results

Using the parameters noted above, the cooperating firm made forecasts for its total array of products manufactured. The average error between forecasted and actual sales for all products was calculated for 3 randomly chosen weeks, and the aggregate error for the first, second, third, and fourth week forecast was 16.7, 19.3, 21.6, and 24.7 percent, respectively.

From the standpoint of error within the OCS, the above errors are overstated. The forecasted sales are used within the OCS to generate feedstuff buy guides. Thus, the error of interest is the difference between the feedstuffs volumes forecasted as needed and those actually needed for the period. To the extent that sales of one product are overforecast and sales of another product are underforecast, the errors are compensating as far as feedstuff needs, if the feedstuffs used in manufacturing both products are similar. The magnitude of this compensating error is difficult to calculate because the firm would have

MISLEADING SALES TREND POSSIBILITIES FORECAST FROM A SMALL DATA BASE



Data are hypothetical.

Figure 4

to operate exactly according to plan to compare actual versus planned error. This seldom occurs in an operational atmosphere; thus, in comparing a planned feedstuff buy with an actual buy for the same period, one obtains only an estimate of the extent of compensating error. However, it is the best available and is certainly of interest. This reduction in error was calculated for 3 randomly selected test weeks, resulting in a value of 6.9, 5.3, 5.1, and 4.6 percent for first, second, third, and fourth week forecasts, respectively. Thus, the aggregate error at the feedstuff buy point (which is the point of true interest) was approximately 9.8, 14.0, 16.5, and 19.6 percent for first, second, third, and fourth week forecasts, respectively.

PROFIT-PLANNING SUBSYSTEM

Compaction

Figure 5 is a macropicture of a block-diagonal LP model of a feed manufacturing system. As previously noted, the model becomes extremely large in terms of number of rows if the firm manufactures an appreciable number of products. Therefore, to have a practical model, from the standpoint of both software constraints and economic processing, the model was compacted using the following logic. Consider for a moment using an individual-product formulation model to determine the optimum ration for just one product. The conventional mathematical statement of the model is as follows:

Minimize $C_1X_1 + C_2X_2 + \ldots + C_nX_n$

Subject to

$$a_{11}X_1 + a_{12}X_2 + \ldots + a_{1n}X_n = b_1$$
$$a_{21}X_1 + a_{22}X_2 + \ldots + a_{2n}X_n = b_2$$
$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots$$
$$a_{m1}X_1 + a_{m2}X_2 + \ldots + a_{mn}X_n = b_m$$
$$X_1 > 0, X_2 > 0, \ldots, X_n > 0$$

where

X_j = feedstuff j

C_j = cost of one unit of X_j

b_i = amount of the i th characteristic allowed in the product

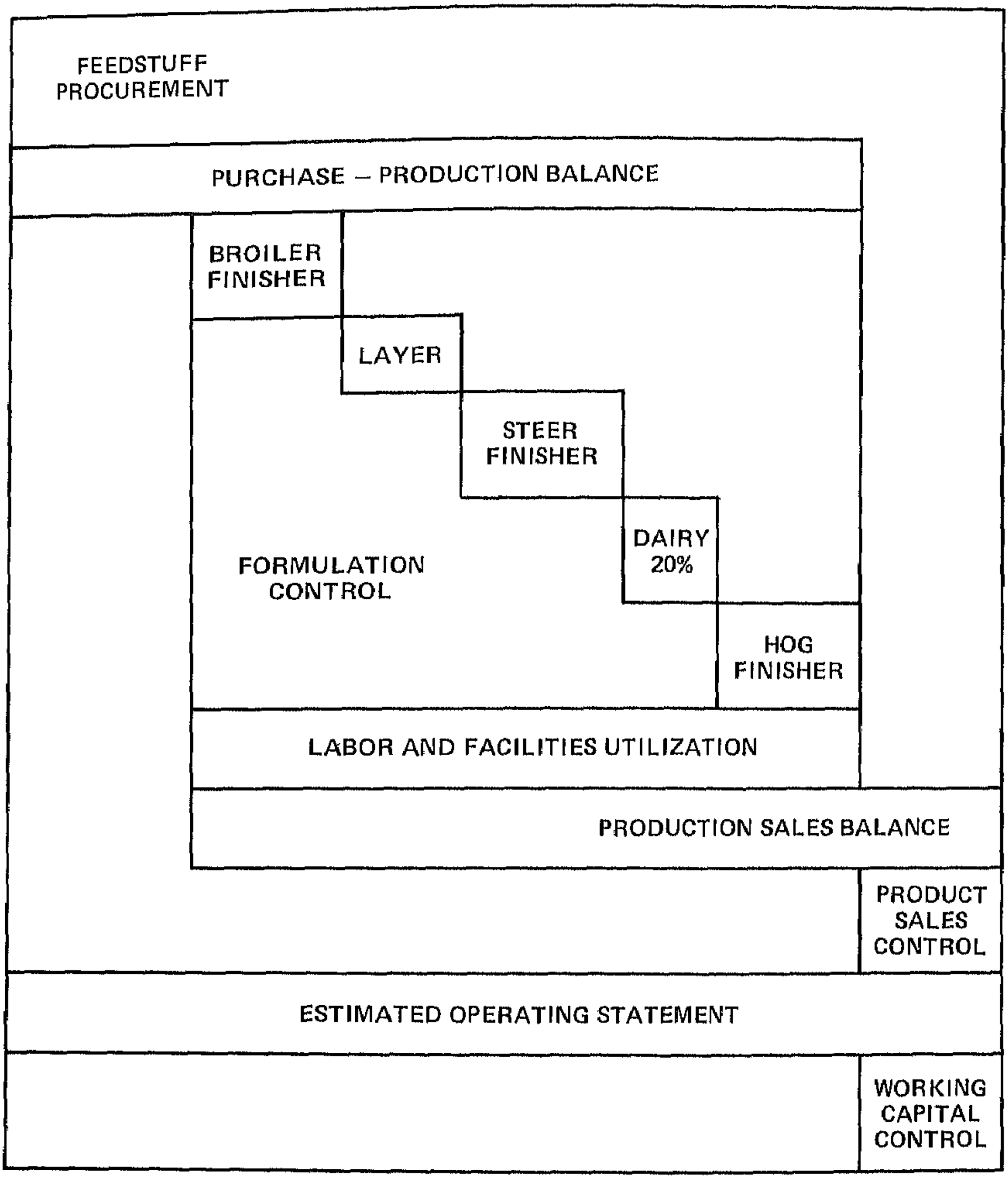
a_{ij} = amount of the i th characteristic that one unit of feedstuff j contributes to the product.

The constraints are nutrient and feedstuff levels that any particular product must possess (that is, "tag specifications"). If a particular ration $X_1^o, X_2^o, \ldots, X_n^o$ satisfies all product specifications and

$$C_1{}^oX_1{}^o + C_2{}^oX_2{}^o + \ldots + C_n{}^oX_n{}^o \le C_1{}^oX_1 + C_2{}^oX_2 + \ldots + C_n{}^oX_n$$

for all possible rations $X_1, X_2 \ldots X_n$ satisfying the product specifica-

MACROPICTURE OF LP MODEL FOR A COMMERCIAL FEED FIRM



Reprinted from (10).

Figure 5

tions, then $X_1^o, X_2^o, \ldots, X_n^o$ is the optimal ration to be used in manufacturing the product when experiencing the feedstuff cost set C_1^o, $C_2^o, \ldots, C_n^o$. Thus, for any feedstuff cost set $C_1^k, C_2^k, \ldots C_n^k$ there will exist a ration $X_1^k, X_2^k, \ldots, X_n^k$ such that $C_1^k X_1^k + C_2^k X_2^k + \ldots + C_n^k X_n^k < C_1^k X_1 + C_2^k X_2 + \ldots C_n^k X_n$ for all possible rations $X_1, X_2, \ldots X_n$ satisfying the product specifications. Call the set of all possible rations L. Then,

$$
\begin{aligned}
l &= l_1, l_2, l_3, \ldots, l_p, l_{p+1} \\
\text{where } l_1 &= X^1_1, X^1_2, \ldots, X^1_n \\
l_2 &= X^2_1, X^2_2, \ldots X^2_n \\
l_3 &= X^3_1, X^3_2, \ldots X^3_n \\
&\vdots \\
l_p &= X^p_1, X^p_2, \ldots X^p_n \\
l_{p+1} &= d_1 l_1, d_2 l_2, \ldots d_p l_p \\
\text{Subject to } & d_1 + d_2 + \ldots + d_p = 1
\end{aligned}
$$

The l_{p+1} member of the set L is actually another set of infinite size containing all the linear combinations of l_1, l_2, and so on through l_p. Given the set L, an alternate method of minimizing the cost of $C_1^k X_1 + C_2^k X_2 + \ldots + C_n^k X_n$ is to search L for the ration l_k which does just that. Since the set L contains all possible rations, again $C_1^k X^k_1 + C^k_2 X^k_2 + \ldots + C^k_n X^k_n \leq C^k_1 X_1 + C^k_2 X_2 + \ldots + C^k_n X_n$ for all possible rations $X_1, X_2, \ldots, X_n$ satisfying the product specifications. The structuring of an LP model so that a search is conducted among rations within the set L to choose the optimal ration for each product results in a significant reduction in the number of equations in the model compared with the number in the conventional block-diagonal model. The formulation-control section of the restructured LP model, hereafter called the compacted-matrix model, is shown in figure 6. The columns within each small block represent different rations (called variations), any one of which may be used to manufacture the product. Feedstuffs are transferred through the variations as a feedstuff supply row, and the levels of the column variations in solution are accumulated and transferred through the variations as a feedstuff supply row, and the levels of the column variations in solution are accumulated and transferred on a sales-demand row. The number of rows in the compacted matrix is equivalent to the number of feedstuffs used by the firm in formulating rations. Fifty is a typical number of feedstuffs used in a commercial firm. Consequently, by using the compacted matrix, the row size for the formulation-control section has been reduced from the 1,200 rows noted in the introduction of this report to 50.

Two simplified planning models were designed, one structured according to the compacted-matrix technique in the formulation-control section(fig. 6) and the other structured according to the block-diagonal formulation-control section(fig. 5). Detailed schematics of the test models are contained in appendix A.

MACROPICTURE OF A COMMERCIAL FEED FIRM'S LP MODEL

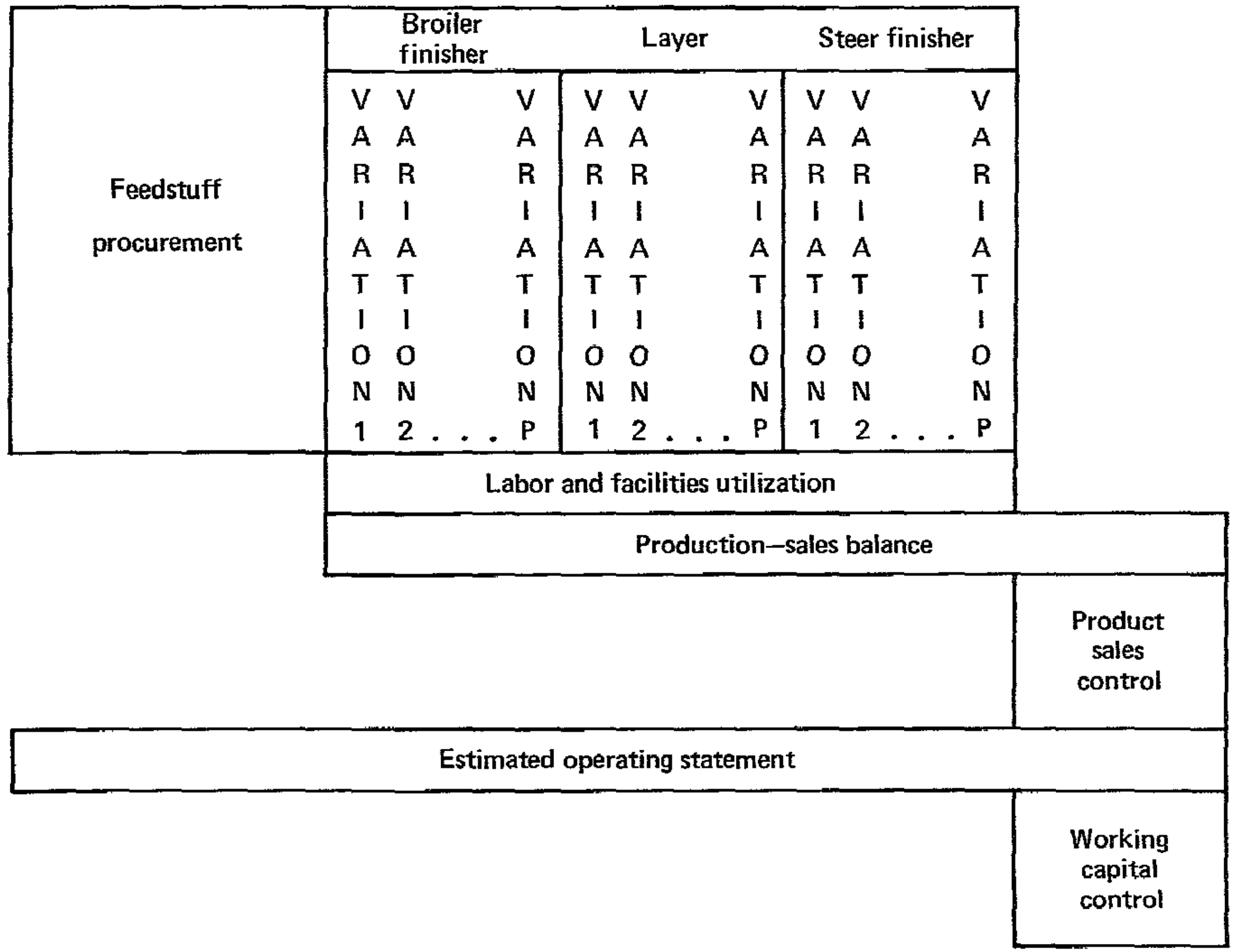


Figure 6

Table 2 --Broiler-finisher rations generated for empirical test

Feedstuff	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
					Lb. feedstuff/lb. of ration 1/					
orn.........	.2846	.2664	.2859	.2859	.2090	.2086	.2086	.2086	.2309	.2086
oultry yproducts ..	.0447	.0087	.0170	.0170	.0418	.0419	.0419	.04.19	.0485	.0419
eather eal 41......	.0151	.0151.	.0151	.0151	.0151	.0151	.0151	.0151	.0151	.0151
olasses, ane.........	.0500	.0500	.0500	.0500	.0500	.0500	.0500	.0500	.0500	.0500
lfalfa eal 17......	.0045	.0033	.0140	.0140	.0001	.0001	.0001	.0001	.0001	.0001
hey.........	.0933	.1009	.1211	.1211	.1059	.1058	.1058	.1058	.1076	.1058
oybean meal 0...........	.0155	.0645	.1796	.1796	.1347	.1345	.1345	.1345	.0465	.1345
orn gluten eal 41......	.0053	.0183	.1239	.1239	.1201	.1201	.1201	.1201	.1395	.1201
lood meal...	0	0	0	0	0	0	0	0	.0346	0
ish meal ...	.0750	.0750	0	0	0	0	0	0	0	0
heat mid-lings.......	.3948	.3913	.1299	.1299	.3089	.3095	.3095	.3095	.3140	.3095
nimal fat ..	.0100	.0100	.0100	.0100	.0100	.0100	.0100	.0100	.0100	.0100
alt.........	.0040	.0040	.0040	.0040	.0040	.0040	.0040	.0040	.0040	.0040
itamin A....	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015
ical. phos..	0	.0046	.0150	.0150	.0126	.0126	.0126	.0126	.0114	.0126
ineral mix..	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015	.0015
otal cost er ton)ollars)....	60.97	62.64	65.55	66.54	67.33	63.10	65.30	62.62	62.90	65.59

' The sum of each column represents 1 pound of ration. For example, the "October ation contained .28 pound of corn (or about one-quarter pound of corn).

Empirical Tests

Since most commercial feed firms formulate rations using an individual-product formulation model, a series of different computer-generated rations for manufacturing each product is presently being produced. The question of whether these rations may be used to form the set L for the profit-planning subsystem must be answered to implement the profit-planning subsystem using the compacted-matrix model. Empirical tests were designed to answer this question and to generate cost-benefit data applicable to the approach. Five products were used in the tests. An actual series of feedstuff prices was used in generating plans.

The products manufactured were broiler finisher, layer, steer finisher, dairy 20%, and hog finisher; the product specifications are listed in appendix table 1. Twenty-five feedstuffs were available for formulation purposes. The nutrient specifications of these 25 feedstuffs are listed in appendix table 2. Monthly series of prices from October 1968 through July 1969 were taken from feedstuffs and are shown in appendix table 3. The monthly feedstuff price series were used to generate one least-cost ration per month per product. These rations comprised the set L. For broiler finisher, the individual rations and associated costs per ton are shown in table 2. For layer, steer finisher, dairy 20%, and hog finisher, the monthly costs per ton are shown in table 3.

Table 3 --Monthly ration costs per ton of layer, steer-finisher, diary-20% and hog-finisher rations generated for empirical test

Product	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
						Dollars				
Layer..........	58.04	59.55	60.11	61.60	62.59	61.93	62.44	64.64	65.06	64.54
Steer finisher.	37.72	38.96	43.13	41.81	42.75	42.05	40.54	40.89	40.11	39.73
Dairy 20%......	38.44	39.60	42.11	42.12	42.96	42.16	40.50	42.68	41.90	41.18
Hog finisher ..	46.58	48.53	50.39	50.57	51.32	48.26	50.08	49.54	49.64	50.10

Results

Structural Comparisons

A comparison of the structural characteristics of the two models proves interesting. The most salient structural difference is that the block-diagonal model contains 336 rows, whereas the compacted-matrix model contains only 79, a savings of 77.5 percent. This is actually an understatement of the percentage savings because most commercially oriented models would contain at least 20 to 30 products, rather than just five products as in the test models. The addition of 20 products would add approximately 1,000 rows to the block-diagonal

model and no rows to the compacted-matrix model. The resultant row savings for the 25-product compacted-matrix model would be 1,257, a percentage savings of 94 percent.

Under most circumstances, the block-diagonal model generates slightly more efficient rations than the compacted-matrix model. Why, then, would anyone use the compacted-matrix model? The answer is because computer hardware (along with the associated LP software) is row-limiting. The block-diagonal version of the commercial feed firm's problem is likely not to fit on many computers, especially those typically used by most firms, and, therefore, will not be economically practical to process. The question then is reduced to determining whether the compacted-matrix model or individual product-formulation model better emulates the block-diagonal model.

The compacted-matrix model can be processed on computers that are typically used by most feed firms to process their accounting data. These computers are usually of sufficient size to handle 200- to 300-row LP problems, which is more than sufficient for processing the compacted-matrix model. Thus, the cost of processing the model is the computer time required. Compare this additional cost with the cost of either renting a large onsite computer or establishing communications with a service bureau (which is really the only practical alternative for many feed firms) to process a block-diagonal model. It is difficult and hazardous to quote specific cost comparisons because of the different circumstances surrounding every commercial feed firm, but a conservative difference of magnitude for processing the two different models is on the order of $100 to $1,000 per week, 11/ in favor of the compacted-matrix model.

As for other structural comparisons between the two models, the block-diagonal model contains 221 vectors, whereas the compacted-matrix model contains 134, a savings of almost 40 percent. The block-diagonal model has a density of 4.13 percent, versus 10.7 percent for the compacted-matrix model.

Economic Comparisons

The block-diagonal and compacted-matrix models were used to generate operational plans for three test situations. The plans were compared for the three test situations to illustrate similarities and differences between the two models. The first test was designed primarily to test the practicality of using rations generated from an individual-product formulation LP model as the set L in the compacted-matrix model. The second and third tests were designed to test the optimality of the compacted-matrix versus the block-diagonal model in allocating for formulation purposes a relatively simple set of feedstuff commitments and then a more complex set of commitments. Also, the third test was used to compare the efficiency of the compacted-matrix model with the individual-product formulation model.

If new ration variations must be generated and placed in the compacted-matrix model every time a slight change occurs in the feedstuff prices, the individual-product formulation model is not a good source of these variations. Therefore, procurement plans were generated for

11/ These figures are based on current technological conditions.

the first test, using the compacted-matrix model, with the following conditions present:

(1) Five hundred tons of each of the five products were manufactured for each of 6 months (February-July) for each of the feedstuff price series for those months (appendix table 3). Thus, a total of 2,500 tons of product was manufactured in each six runs.

(2) No feedstuff commitments were made, thus blocks 11-51 and 14-51 were not utilized. All feedstuff purchases were made via the current market, block 10-50.

(3) At first, all ration variations generated using the individual-product formulation model prior to the current month's feedstuff price series were allowed in the set L. In other words, if products were being manufactured using the feedstuff price set for February, individual optimum-cost rations generated using the price sets for October, November, December, and January were allowed in the set L. The model was then systematically resolved, reducing the number of active variations, dropping the oldest first.

If the compacted-matrix model can generate efficient procurement plans using ration variations that were generated using price sets that are at least 1 month old, it is not necessary to generate a new set of ration variations every time the compacted-matrix model is processed.

The results of the test run were encouraging. As long as four or more of the most recent ration variations were allowed in the set L, the loss in efficiency was quite modest. The average loss was $205, or approximately 8 cents per ton. As the number of ration variations was reduced further, ration costs rose rapidly. Table 4 lists the individual losses for the different months as the number of variations in the set L was reduced. Note the rapid increase in losses as the number of variations reduced below four. The average loss when only the ration variation formulated in the price set prevailing the preceding month was allowed was $431, or approximately 17 cents per ton.

Thus, it is possible to use the individual-product formulation model to generate ration variations for the set L. Using four ration variations that are <u>at least</u> 1 month old, the loss would be only 8 cents per ton when compared with the block-diagonal model. When this loss is balanced against the additional processing cost for the block-diagonal model, the loss would be negligible or probably would result in a net savings for the compacted-matrix model.

The second test run was designed to evaluate the efficiency of the compacted-matrix model in allocating, for formulation purposes, a rather simple set of commitments. Note that the loss incurred in the first test using the compacted-matrix model is due entirely to the lack of the most up-to-date ration variations in the set L. However, if the most up-to-date ration variations were the only worry, the ration variations could be obtained easily by using an individual-product formulation model. What is of true concern are the optimum rations when considering the cost and volume of committed feedstuffs (and more generally, other operational constraints) in addition to the prices of current

feedstuffs. To satisfv this concern, procurement plans were generated using the compacted-matrix model with the following conditions present:

1. Five hundred tons of each of the five products were manufactured for each of 6 months (February-July) for each of the feedstuff price series for those months (appendix table 3). Thus, a total of 2,500 tons of product was manufactured in each of the six runs.

2. Six hundred tons of corn at $38 per ton, 700 tons of yellow hominy at $42 per ton, and 200 tons of 50-percent soybean meal at $75 per ton were committed in each of the six runs. The deferment cost (block 14-51) for the committed feedstuffs was 15 cents per ton.

3. At first, all ration variations generated using the individual-product formulation model prior to the current month's feedstuff price series were allowed in the set L. The model was systematically resolved, reducing the number of active variations, by dropping the oldest first.

In other words, test 2 conditions are the same as for the first test, except for the commitments.

Table 4 --Losses resulting from use of the compacted-matrix model with differing numbers of variations active in set L (test 1)1/

Variations 2/	Losses by month						Average
	Feb.	March	April	May	June	July	
				Dollars			
1	182	801	613	318	220	453	431
2	182	801	495	108	220	350	359
3	182	569	205	108	147	323	256
4	182	283	196	108	147	323	206
5		208	196	108	147	264	185
6			196	108	147	264	179
7				108	147	264	173
8					147	264	205
9						264	264

1/ Minimum of 1-month lag in ration variations. Difference in cost of producing 2,500 tons of feed using compacted-matrix versus using block-diagonal model.

2/ Number of ration variations active in set L of compacted-matrix model.

As long as four or more of the most recent ration variations were allowed in the set L, the loss in efficiency was again quite modest. The average loss was $253, or approximately 10 cents per ton. As the number of ration variations was reduced further, ration costs rose rapidly. Table 5 shows the individual losses for the different months as the number of variations in the set L was reduced. Again, note the rapid increase in losses as the number of variations was reduced below four. The average loss when only the ration variation formulated using the preceding month's price set was allowed was $590, or approximately 24 cents per ton.

Table 5--Losses resulting from use of the compacted-matrix model with differing numbers of variations active in set L (test 2) 1/

Variations 2/	Losses by month						Average
	Feb.	March	April	May	June	July	
				Dollars			
1	175	565	784	480	283	1,254	590
2	175	565	666	269	203	648	421
3	175	346	375	201	195	540	305
4	175	150	367	201	142	483	253
5		150	304	186	142	402	237
6			304	186	129	402	255
7				106	129	396	210
8					129	345	237
9						345	345

1/ Minimum of 1-month lag in ration variations. Difference in cost of producing 2,500 tons of feed using compacted-matrix model versus block-diagonal model.

2/ Number of ration variations active in set L of compacted-matrix model.

As mentioned above, the third test was designed to (1) show the relative efficiency of the compacted-matrix model as compared with the block-diagonal model in generating procurement plans when a relatively more complex set of commitments is considered than in the second test and (2) to show the relative efficiency of the compacted-matrix model as compared with the individual-product formulation model. Procurement plans were generated using the compacted-matrix model with the following conditions present:

1. Five hundred tons of each of the five products were manufactured for each of 6 months (February-July) for each of the

feedstuff price series for those months (appendix table 3). Thus, a total of 2,500 tons of product was manufactured in each of the six runs.

2. One thousand tons of corn at $24 per ton, 100 tons of 17-percent alfalfa meal at $41 per ton, 100 tons of 50-percent soybean meal at $81 per ton, and 300 tons of wheat middlings at $41.25 per ton were committed in each of the six runs. The deferment cost (block 14-51) for the committed feedstuffs was $5 per ton.

3. All ration variations generated using the individual-product formulation model, <u>including</u> a set generated from the current month's feedstuff price series, were allowed in the set L.

The ration variations generated using the individual-product formulation model and the current month's feedstuff price series were allowed in the set L to demonstrate that these rations may not be the optimum rations; in fact, they may be extremely suboptimum. If this is true, use of the individual-product formulation model results in the use of suboptimum rations no matter how recently the rations were generated.

The commitment volume represents 60 percent of the total volume of feedstuffs needed to manufacture the 2,500 tons of product. The commitments are representative of the type and volume of commitments that any judicious buyer would probably have made for production 1 to 3 weeks hence. The commitments represent an attempt to purchase a large portion of the low-, medium-, and high-protein feedstuffs required for manufacturing. Since the period for which manufacturing was being planned was near, there would have been little time remaining to cancel any commitments; therefore, the cost of deferring, rerouting, or delaying commitments was placed at $5 per ton. This cost will vary from firm to firm, depending on storage facilities, geographical location, and other related factors.

To determine the difference in optimality between the compacted-matrix model and the individual-product formulation model, the compacted-matrix model was processed a second time with all ration variations inactive except the subset generated using the feedstuff price series for the month of procurement. This, in effect, forces the committed and currently available feedstuffs through the latest individually generated rations so that a total manufacturing cost can be derived. The total cost of manufacturing the 2,500 tons of product for each of the 6 months, using the three models, is shown in table 6. The use of rations generated by the compacted-matrix model resulted in an average loss of $286 per 2,500 tons of product as compared with use of rations generated by the block-diagonal model. The use of rations generated by the individual-product formulation model resulted in an average loss of $2,259, or an average loss of $1,973 per 2,500 tons of manufactured feed, a loss of almost 80 cents per ton.

Proponents of the individual-product formulation model may argue that test 3 was unfairly structured because current rather than committed prices were used for the four feedstuffs for which commitments were made. It would be revealing to generate rations using the individual-product formulation model and committed prices for the affected feedstuffs, because current prices of feedstuffs would not

Table 6--Manufacturing cost and comparative losses resulting from the use of different test models to generate monthly procurement plans to satisfy test-3 requirements, 1969

Month	Block-diagonal model	Compacted-matrix model	Individual-product formulation model
		Dollars	
February	1/128,737	129,215 2/(978)	131,169 (2,332)
March	128,217	128,486 (270)	130,634 (2,417)
April	127,245	127,514 (269)	129,349 (2,104)
May	128,737	139,015 (278)	131,178 (2,441)
June	128,207	128,437 (230)	130,681 (2,474)
July	128,667	128,863 (206)	120,254 (1,687)
Average cost	128,302	128,588 (286)	130,561 (2,259)
Loss per ton		(11.5¢)	(90.5¢)

1/ Indicates manufacturing cost.

2/ Numbers in parentheses indicate comparative losses.

be taken into account when it is economically desirable to use a greater quantity of a feedstuff than is committed. The optimum mix of committed and current purchase volumes for feedstuffs is not known a priori; therefore, the optimum weighted prices are not known. Since these factors are not known, the compacted-matrix and block-diagonal models are much more efficient. Output from these models gives the optimum mix of committed and current purchase volume of feedstuffs to manufacture a desired volume of product.

Finally, savings resulting from the use of the compacted-matrix model, rather than the individual-product formulation model, may be greater than those just noted for at least two reasons. First, only five products were manufactured rather than the typical 20 to 40 products. As the number of products in a model increases, the total number of ration variations increases. Thus, the possibility increases that particular rations may be present that more efficiently utilize any particular set of commitments and currently available feedstuffs. Second, the test models are subsets of the more general model pictured for a commercial feed firm (fig.5). The potential savings

resulting from more efficient use of such resources as facilities, labor, and capital have not been included in these savings.

IMPLEMENTATION

Static Considerations

The physical flow of feedstuffs through a commercial feed mill and the physical restrictions which affect this flow are pictured in figure 7. Since major costs are incurred in each block in the figure, the primary question in the shorter run becomes one of balancing these costs to obtain a maximum profit per delivered unit of product. Although the arrows indicate the proper flow of the feedstuffs, the flow of influence is in the opposite direction. That is, potential sales should determine finished-product inventory levels, production, feedstuff inventory levels, and purchases. This flow of influence and its relationship to the OCS is shown in figure 8.

Assuming potential sales as given for a moment, management may improve profits (or decrease losses) through improved purchasing of feedstuffs and manufacturing and distribution of products. Since feedstuff costs are typically 80 percent or more of total product costs, a small improvement in procurement decisionmaking, versus manufacturing or distribution decisionmaking, reflects the greatest percentage decrease in total product costs. It is therefore imperative that a useful OCS for the commercial feed firm give specific guidelines for the procurement of feedstuffs in such a mix that a minimum-cost buy results. The OCS is capable of giving knowledge concerning the specific recommendations as to procurement of feedstuffs if, in addition to the physical restrictions noted in figure 7, data and information are available concerning the following:

(1) Product specifications

(2) Prices and quantities of committed and inventoried feedstuffs

(3) Penalty cost for deferment or disposal of committed feedstuffs.

(4) Prices of feedstuffs available for immediate delivery and any upper limits as to quantities that may be ordered

(5) Projected product sales volumes and prices.

If these input data are available for the period to be analyzed and if manufacturing and administrative restrictions have been described correctly in the OCS, processing the OCS with this data is tantamount to manufacturing products for the period of interest. To plan for the specified decision period, management utilizes several reports, including individual summaries of feedstuff consumption, commitment, inventory, and product sales.

PHYSICAL FLOW OF FEEDSTUFFS AND PHYSICAL RESTRICTIONS AFFECTING FLOW THROUGH A COMMERCIAL FEED MILL

PURCHASES →	INVENTORY →	PRODUCTION →	INVENTORY →	SALES
1. Commitments 2. Current availability 3. Transportation availability 4. Unloading capability 5. Rolling stock	1. Bin availability 2. Bin flowability 3. Prior bin assignments 4. Deterioration rate 5. Transfer	1. Labor availability 2. Equipment availability	1. Storage availability 2. Deterioration rate 3. Transfer capability 4. Rolling stock	Delivery capability

Figure 7

FLOW OF INFLUENCE THROUGH A COMMERCIAL FEED MILL AND ITS RELATIONSHIP TO AN OCS

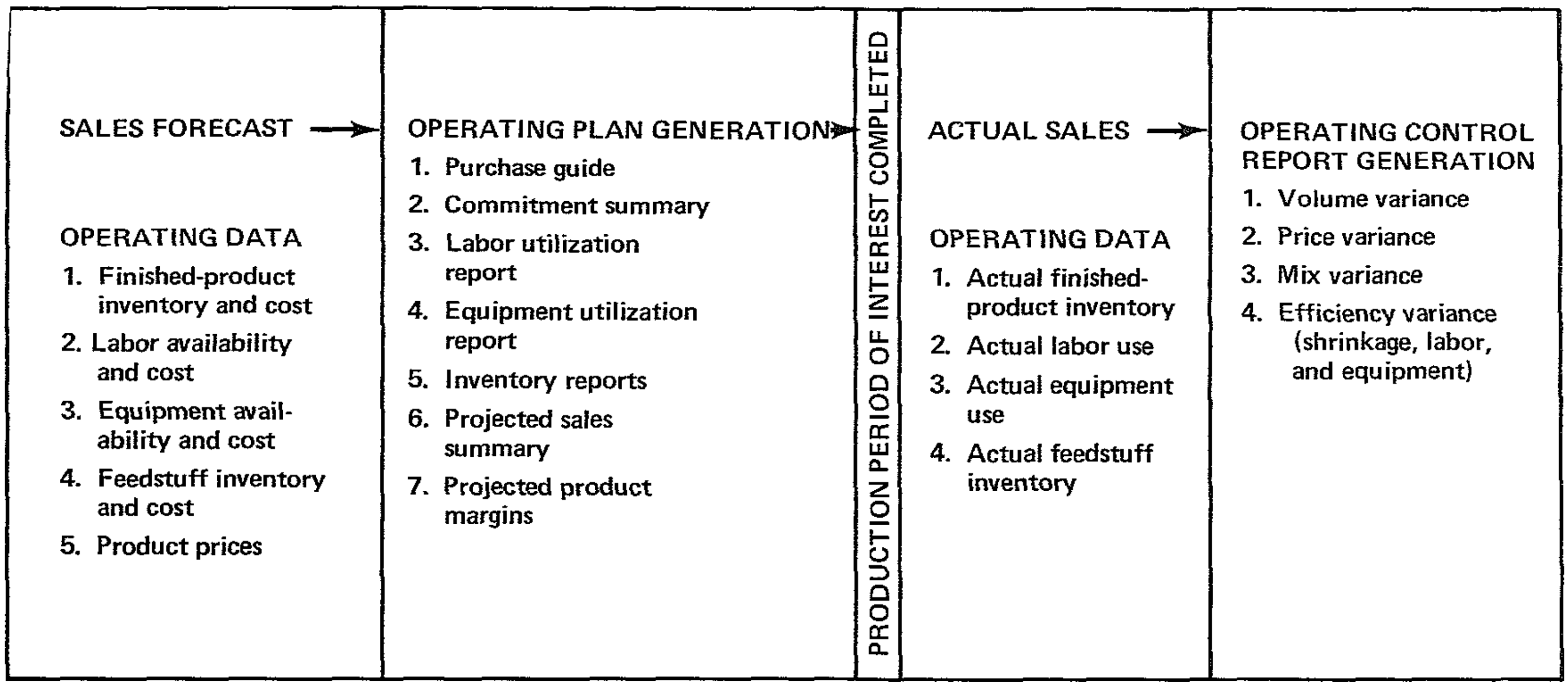


Figure 8

Dynamic Considerations

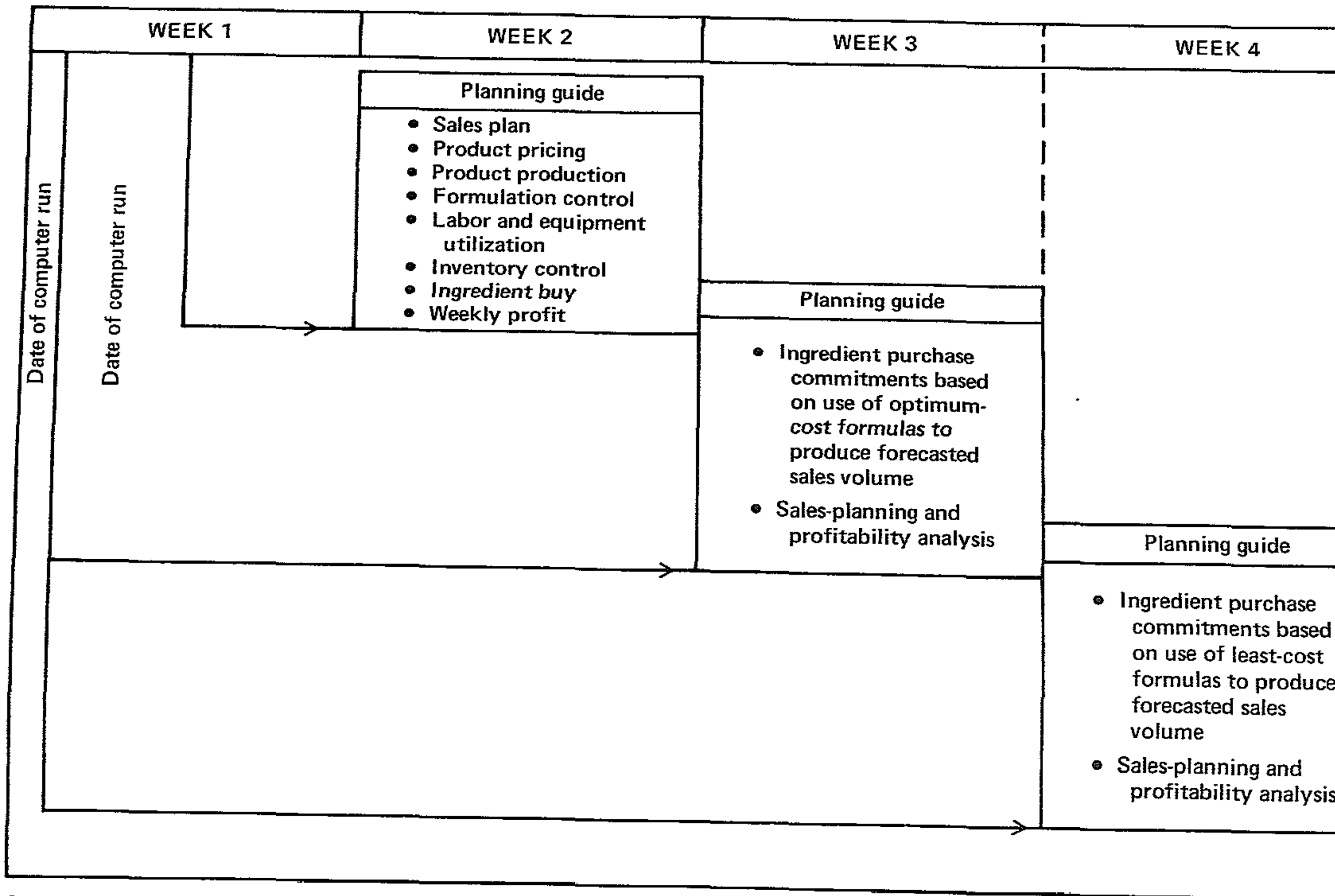
The assurance that feedstuff prices change constantly is probably the one point on which the entire management team of a commercial feed firm will agree. However, to process the OCS requires that management specify the prices of both feedstuffs and products. How can the static, deterministic system be used in the dynamic environment in which the commercial feed firm operates?

First, there can be a systematic reprocessing of the OCS, using updated input data, as management zeros in on the target period of production. For example, depending upon the lead time required by any particular firm, the OCS could be used to generate decision guides for individual weeks ahead. For example, in the forthcoming week, the first, second, and third week plans previously generated would be reprocessed as first, second, and third week plans. An illustration of this type of planning schedule is given in figure 9. If conditions facing management change drastically within a week, there is certainly no reason why the OCS could not be recycled specially to interpret the new conditions. However, it is important, when conditions change, that this mode of operation is not substituted for management information already available. That is, information is available from a static model such as the OCS which can be used in determining reaction to dynamic conditions. A report illustrating such information is the projected penalty costs for the use of feedstuffs not chosen as "good buys" when the OCS was last processed.

A suggested format for the report of projected penalty costs is shown in table 7. The first column is the source of the feedstuff, and the second column is the suggested price at which the feedstuff becomes a desirable buy. The third column is a penalty cost per ton for using the feedstuffs listed. The fourth column is the summation of columns two and three which gives the cost per ton of each feedstuff. Note that the OCS generates only one set of feedstuff penalty costs, whereas with the single-product formulation model there is a set generated for every ration formulated. Assuming the market and technical conditions faced by the firm have not changed since the processing of the OCS, the projected feedstuff penalty cost report gives an indication of the total penalty to the firm, whereas an individual-formulation penalty report gives an indication of the penalty to the firm only when the product for which the ration was developed is being manufactured.

If the dynamics of the market are such that a feedstuff, listed as available currently and shown as a purchase the last time the OCS was processed, suddenly becomes unavailable, management, using the OCS, can investigate the possibility of purchasing feedstuffs that were not shown as desirable purchases previously, having some indication of the relative penalties for purchasing them. Similarly, if there is a sudden drop in the price of one if the feedstuffs, the projected penalty cost can be investigated to determine if the drop is great enough to cause the feedstuff to become a desirable buy. If the feedstuff has the potential of being used in large volumes in the products of the firm, this generally would be a sufficient reason for recycling the OCS. Additional information is available from a

GENERATION OF PROFIT PLANS THROUGH SYSTEMATIC REPROCESSING OF THE OCS



Reprinted from (10).

Figure 9

Table 7 --Illustrative feedstuff penalty-cost report 1/

Feedstuff	Source	Buy price	Penalty cost	Cost
		Dollars per ton		
Corn	Rail	40.00	6.00	46.00
Tankage	Truck	93.61	8.89	102.50
Cottonseed meal . . .	Rail	---	71.90	71.90
Alfalfa meal 17 . . .	Truck	36.00	5.60	41.60
Soybean meal 50 . . .	Rail	6.00	10.50	86.50
Yeast, brewers . . .	Storage	19[illegible].70	18.10	216.80
Wheat middlings . . .	Rail	36.25	5.25	41.50
Citrus pulp	Rail	29.48	21.92	51.40

1/ Figures are for illustration only and bear no relationship to any part of the study.

static model such as the OCS when prices, constraints, and coefficients are systematically changed.12/ This process is commonly called sensitivity analysis. The additional information obtained from sensitivity analysis is often as valuable or more so in interpreting dynamic changes than the optimum solution to the system. Another point is that the additional cost is so minimal that it is unfortunate if management has provided the input and the OCS for producing an optimal solution and is not in return given the additional information from a sensitivity analysis of the optimal solution.

Sensitivity analysis is important for several reasons. One is that it can give indications as to the stability of the optimal solution when parameters change. For example, the railroad delivery situation may be such that it is doubtful whether a particular feedstuff will be availabl for a specified period. The availability of this feedstuff can be systematically reduced in the OCS, and the effect studied. If the total profit of the new optimal solution differs little from the original solution, management may want to institute the latter generated plan to negate the possibility of having to change manufacturing plans at the last minute.

12/ For a good exposition, see Hillier and Lieberman, Introduction to Operations Research, San Francisco: Holden-Day, 1967, p. 499.

The OCS can also generate the contribution margin for each product. The contribution margin is the return above feedstuff costs that will result from manufacturing and selling one more unit of a product than is called for in the present forecast. Through sensitivity analysis, it is possible to determine the range of volume over which this contribution margin remains the same. Information concerning the contribution to profit and the sensitivity of forecasted product prices and volumes is illustrated in table 8.

If the goal of the firm is a $20 manufacturing margin, then the $38.53 margin on hog finisher (table 8) prompts some interesting questions concerning the pricing of the product. If the $75 price is competitive, should one hold the price line and reap the extra margin or lower the price and try to capture additional volume? Columns 3 and 5 are the lower limit and upper limit, respectively, to which the sales volume of each product may vary without causing a switch in the optimum-formula variation. Note that the upper limit on steer finisher is only 35 tons greater than forecasted sales. If marketing conditions for steer finisher become significantly more favorable, a reprocessing of the OCS may be in order.

Another interesting question that occurs when analyzing output from an OCS is, "What is/are the interrelationship(s) causing a penalty-cost or volume range to be the value it is?" Nelson (9) has extracted more dynamic implications from the static LP model by asking questions similar to the one above. The forecast of sales traditionally has been inserted into an OCS at a specified level--lower and upper limits in addition to equality limits. With this type of model, the interpretation of output changes significantly. For example, in table 3 the contribution margin is the return above feedstuff costs that will result from manufacturing and selling one more unit of a product than was called for in the present forecast given to the OCS. With the possibility that sales may vary, the interpretation of the contribution margin becomes even more subtle. Rather than the contribution margin repre-

Table 8--Illustrative projected product price and sales report

Product	Projected price	Projected sales	Contribution		
			Margins	Lower limit	Upper limit
	Dols./ton	Tons	Dols./ton	Tons	Tons
Broiler finisher	82.00	500	20.70	0	592
Layer	80.00	500	19.32	218	710
Steer finisher	60.00	500	20.90	0	535
Dairy 20%	60.00	500	18.97	307	963
Hog finisher	75.00	500	38.53	15	633

senting the return above feedstuff costs, it may just as well represent the additional return from producing sufficiently less of other products to allow raw materials (feedstuffs) for the manufacture of the high-profit-margin product. For a firm producing branded products, sensitivity information of this type can be invaluable in promotion and advertisement planning. The possibility of altering the product mix to improve the profit picture is not new to management, but the use of LP to provide guidelines has certainly not been exploited by the feed industry.

Conculsion

Utilizing the OCS, rather than an efficient single-product formulation model, the cooperating firm was able to reduce its manufactured costs per ton of product approximately 84 cents. This type of savings resulted not simply from blind use of information provided by the OCS but from imaginative use of information by the management of the cooperating firm and from the dynamic implications of the static model.

LITERATURE CITED

1. Brown, Robert G.
   1963. Smoothing, Forecasting and Prediction of Discrete Time Series. Englewood Cliffs, N.J. : Prentice-Hall, Inc.

2. Conway, R. W., Maxwell, W.L., and Miller, L.W.
   1967. Theory of Scheduling. Reading, Mass: Addison Wesley Co.

3. Dorfman, R., Samuelson, P.A., and Solow, R.M.
   1958. Linear Programming and Economic Analysis. N.Y. : McGraw-Hill Co.

4. Dudley, William A., and Parks, John R.
   1966. Non-Linear Profit Maximization. Feedstuffs 38(30): 42-43.

5. Funk, Thomas F.
   1968. A Systems Approach to Market Planning: Application to the Seed Corn Industry. Unpublished M.S. thesis, Purdue University, Ind.

6. Hays, Jr., A.H.
   1967. An Economic Feasibility Study of Least Cost Formulation in the Small Plant. Feedstuffs 39(8): 22-26, 64-66.

7. Hutton, Robert
   1964. The Changing Character of the "Feedmix Problem" Feedstuffs 36(5): 26-27, 30-31.

8. Johnson, R.A., Kast, F.E., and Rosenzweig, J.E.
   1963. The Theory and Management of Systems. N.Y.: McGraw-Hill Co.

9. Nelson, Larry L.
   1971. Implementation of Large Scale Planning Systems: A Study of Computational Dynamics and Managerial Interface. Unpublished Ph.D. thesis, Purdue University, Ind.

10. Snyder, J.C., Nelson, L.L., and Guthrie, T.L.
    1969. Profit Planning and Control: A Computer Oriented System for Feed Industry Management. Chicago Amer. Feed Man. Assoc.

11. Snyder, James C., and Swackhammer, Gene L.
    1966. Management Planning and Control Systems. Lafayette, Ind.: Purdue University Agricultural Experiment Station, Research Bulletin No. 809, June.

12. Stafford, Joseph H., and Snyder James C.
    1964. Applications of An Assembly Model in the Feed Industry. Lafayette, Ind.: Purdue University Agricultural Experiment Station, Research Bulletin No. 773, March.

13. Swackhammer, Gene L.
1966. A Management Control System for Processed Meat Firms. Unpublished Ph.D. thesis, Purdue University, Ind.

14. Waugh, Frederick V.
1951. The Minimum Cost Dairy Feed. Am. Jour. of Agr. Econ. 33(3): 299-310.

15. Winters, Peter R.
1960. Forecasting Sales by Exponentially Weighted Moving Averages Mgt. Sci. 6(3): 324-342.

Appendix A. Schematics of Empirical Test Models

Schematic representations of the block-diagonal and compacted-matrix models are given in figures A-1 and A-2. The following sections were included in the models:

(1) Current market purchase of feedstuffs

(2) Current market availability of feedstuffs

(3) Use or deferment of committed feedstuffs

(4) Feedstuff purchase-product formulation balance

(5) Product formulation (using block-diagonal or compacted-matrix model construction)

(6) Product formulation-sales balance

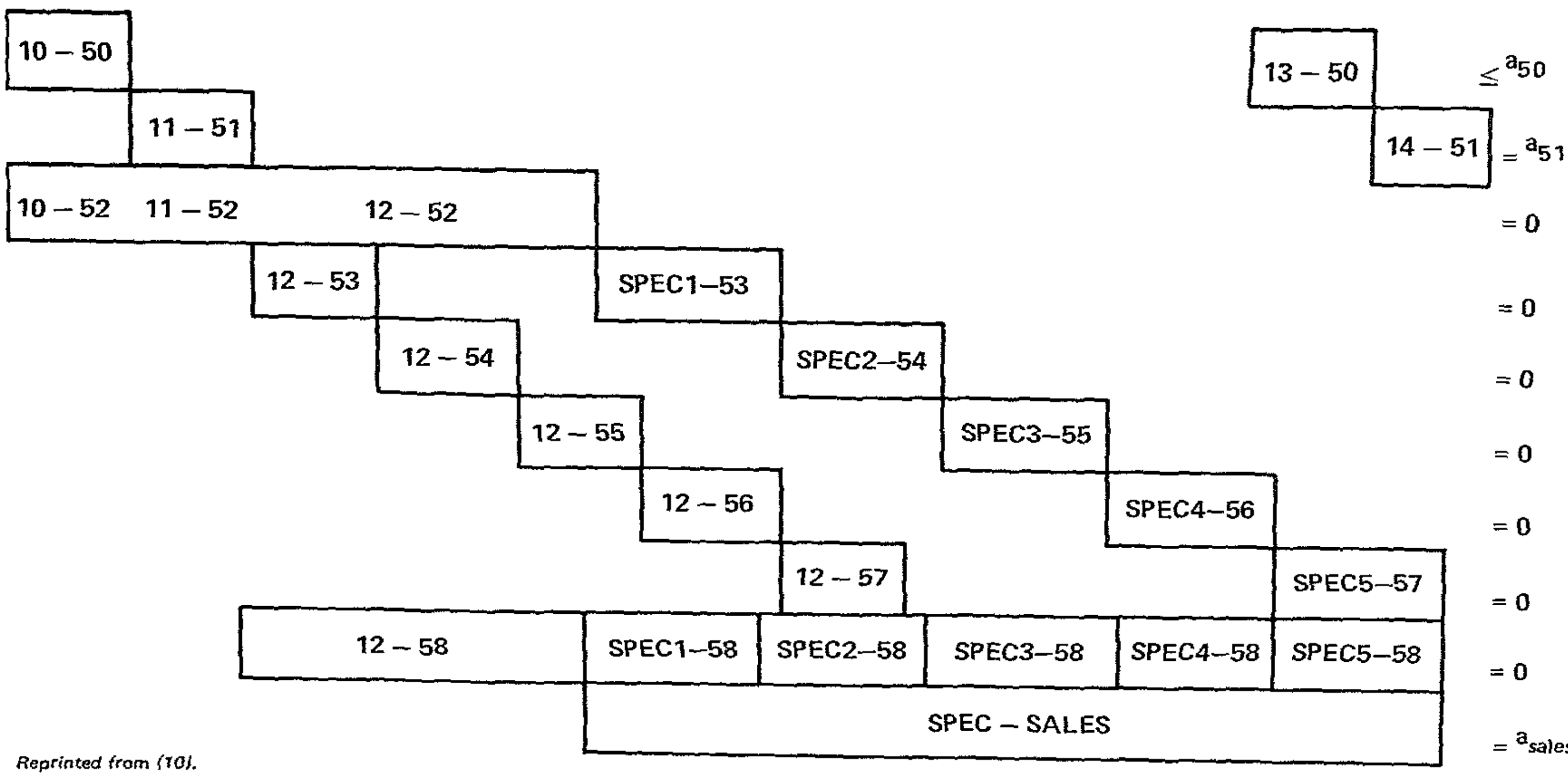
(7) Product sales control.

Blocks 10-50, 13-50, 11-51, and 14-51 represent the potential supplies of feedstuffs. The blocks are identical in both models. Current market purchases of feedstuffs are available through block 10-50. If quantities of feedstuffs greater than availabilities (a_{50}) are required, special purchases at a premium price are available through block 13-50. Committed feedstuffs (a_{51}) are available through block 11-51. Commitments may be deferred or disposed through block 14-51. Blocks 10-52 and 11-52 represent transfer of feedstuffs to the formulation section of the model. The blocks are identical in both models.

Block 12-52 in the block-diagonal model represents transfer of feedstuffs to the formulation of individual products. Blocks 12-53, 12-54, 12-55, 12-56, and 12-57 represent the nutrient analyses of the feedstuffs which are appropriate for each of the five products. Blocks SPEC1-53, SPEC2-54, SPEC3-55, SPEC4-56, and SPEC5-57 represent the product specifications for each of the five products. Blocks 12-58, SPEC1-58, SPEC2-58, SPEC3-58, SPEC4-58, SPEC5-58, and SPEC-SALES represent a transfer of products from formulation to product sales (a_{sales}).

Block 12-52 in the compacted-matrix model represents the set L of different rations (variations) which may be used to manufacture the five products. Block 12-SALES represents a transfer of products from formulation to sales (a_{sales}).

SCHEMATIC OF BLOCK-DIAGONAL TEST MODEL



Reprinted from (10).

Figure A-1

SCHEMATIC OF COMPACTED-MATRIX TEST MODEL

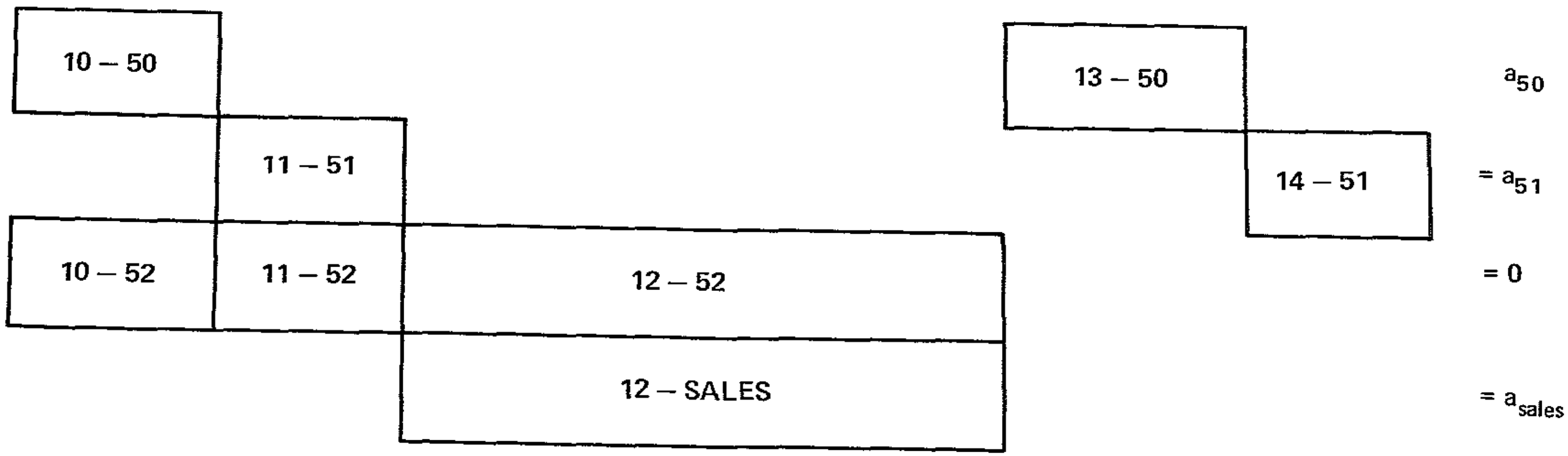


Figure A-2

APPENDIX B. TABLES

Appendix table 1 --Specifications of products used in empirical tests

Code & identification	Units/cwt.1/	Broiler finisher		Layer		Steer finisher		Dairy 20%		Hog finisher	
		LL2/	UL3/	LL	UL	LL	UL	LL	UL	LL	UL
Net energy	Calories	0	NUL4/	0	NUL	6,800	NUL	7,400	NUL	900	NUL
Prod. energy	Calories	600,000	NUL	900,000	NUL	0	NUL	0	NUL	0	NUL
Protein (crude)		0	NUL	0	NUL	11.5	NUL	20	NUL	13	17
Protein (digest.)		0	NUL	0	NUL	9.5	NUL	0	NUL	0	NUL
Arginine		1.03	NUL	.5	NUL	0	NUL	0	NUL	0	NUL
Lysine		1.03	NUL	.625	NUL	0	NUL	0	NUL	.66	NUL
Methionine		.38	NUL	.299	NUL	0	NUL	0	NUL	.44	NUL
Meth. + cyst.		.725	NUL	.509	NUL	0	NUL	0	NUL	.11	NUL
Tryptophane		.185	NUL	.143	NUL	0	NUL	0	NUL	0	NUL
Glycine		.8	NUL	.200	NUL	0	NUL	0	NUL	0	NUL
Fat		0	NUL	0	NUL	0	NUL	0	NUL	0	NUL
Fiber		0	4	0	6	8	12.5	0	NUL	0	5
Calcium		.8	NUL	2.75	NUL	.5	.9	.3	NUL	.48	.8
Phosphorus (total)		0	NUL	0	NUL	.3	.5	.4	NUL	.44	.65
Phosphorus (available)		.4	NUL	0	NUL	0	NUL	0	NUL	0	NUL
Niacin	Milligrams	2,000	NUL	1,500	NUL	0	NUL	0	NUL	500	NUL
Riboflavin	" "	250	NUL	160	NUL	0	NUL	0	NUL	100	NUL
Pantothenic acid	" "	650	NUL	300	NUL	0	NUL	0	NUL	450	NUL
Choline	" "	65,000	NUL	43,000	NUL	0	NUL	0	NUL	0	NUL
Vitamin A	MIU	.3	NUL	.4	NUL	0	NUL	0	NUL	0	NUL
Corn		10	NUL	10	NUL	0	NUL	0	NUL	0	NUL
Meat meal		0	5	0	10	0	NUL	0	NUL	0	5
Poultry byproduct		0	5	0	5	0	NUL	0	NUL	0	5
Feather ml. 41		0	2.5	0	2.5	0	NUL	0	NUL	0	5
Cottonseed		0	5	0	0	0	NUL	0	NUL	0	10
Molasses, cane		0	5	0	5.0	0	15	0	10	0	5
Urea		0	0	0	0	0	1	0	2	0	0
Alfalfa meal 17		0	NUL	2.5	NUL	2.5	15	0	NUL	0	21.5
Hominy, yellow		0	NUL	0	NUL	0	NUL	0	NUL	0	20
Whey		0	NUL	0	NUL	0	NUL	0	NUL	0	5
Peanut meal		0	NUL	0	NUL	0	NUL	0	NUL	0	10
Soybean meal		0	NUL	0	NUL	0	NUL	0	NUL	0	NUL
Corn gluten ml. 41		0	NUL	0	NUL	0	NUL	0	NUL	0	5
Corn gluten feed		0	NUL	0	NUL	0	NUL	0	NUL	0	NUL
Blood meal		0	NUL	0	NUL	0	NUL	0	NUL	0	3
Yeast, brewers		0	NUL	0	NUL	0	NUL	0	NUL	0	5
Fishmeal (menhaden)		0	7.5	0	5	0	NUL	0	NUL	0	7.5
Wheat middlings		0	NUL	0	NUL	0	40	0	35	0	20

See not[illegible]

Continued

Appendix table 1 --Specifications of products used in empirical tests --Continued

Code & Identification	Units/Cwt.1/	Broiler finisher		Layer		Steer finisher		Dairy 20%		Hog finisher	
		LL2/	UL3/	LL	UL	LL	UL	LL	UL	LL	UL
Rice bran		0	NUL	0	NUL	0	35	0	35	0	20
Citrus pulp		0	NUL	0	NUL	0	50	0	33	0	NUL
Animal fat		1	15	0	15	0	5	0	41	2	10
Salt		.4	.4	.35	.35	.5	.5	1	1	.5	.5
Vitamin A		.15	NUL	.2	NUL	.1	NUL	.2	NUL	.1	NUL
Dicalcium phos.		0	NUL	0	NUL	0	NUL	0	NUL	0	NUL
Vitamin B-12		0	NUL	0	NUL	0	NUL	0	NUL	0	NUL
Trace mineral mix		.15	.15	.1	.1	0	NUL	0	NUL	.1	.1

1/ Units are lbs. of nutrient or feedstuff per cwt. of product, except where noted otherwise.
2/ LL = lower limit.
3/ UP = upper limit.
4/ NUL = no upper limit.

Appendix table 2--Nutrient specifications of feedstuffs available in empirical test

Nutrient	Units/lb. 1/	Corn	Meat meal	Poultry byproducts	Feather meal	Cotton-seed meal	Cane molasses	Urea
Net energy	Calories	78	70	0	68.5	75	49	0
Product energy	Calories	1100	800	900	600	690	715	0
Protein (crude)		.089	.60	.58	.85	.41	.03	262.0
Protein (digest)		.058	.499	0	.701	.329	0	196.5
Arginine		.004	.03	.031	.056	.041	0	0
Lysine		.0021	.035	.032	.015	.017	0	0
Methionine		.0018	.007	.010	.0051	.006	0	0
Meth. + cyst.		.0034	.01	.009	.0351	.014	0	0
Tryptophane		.0007	.008	.0068	.0057	.005	0	0
Glycine		.0003	.066	.071	.068	.019	0	0
Fat		.038	.08	.12	.025	.035	0	0
Fiber		.029	.03	.025	.015	.13	0	0
Calcium		.0001	.06	.036	.002	.0015	.05	0
Phosphorus (total)		.0025	.03	.022	.0075	.01	.0005	0
Phosphorus (available)			.03	.022	.0075	0	0	0
Niacin	Milligrams	9	17	18	.076	.17	16	0
Riboflavin	Milligrams	.50	1	4	.008	.018	1	0
Pantothenic acid	Milligrams	2.2	1	4	.035	.16	17	0
Choline	Milligrams	200	1,000	2,720	400	1,200	300	0
Vitamin A	MIU	.0015	0	0	0	0	0	0

1/ Units are lbs. of nutrient per lb. of feedstuff except where noted otherwise.

Continued

Appendix table 2--Nutrient specifications of feedstuffs available in empirical test-- options

Nutrient	Alfalfa meal	Yellow hominy	Whey	Peanut meal	Soybean meal 50	Corn gluten meal 41	Corn gluten feed	Blood meal
Net energy	42.5	80	79	66	76	79	68	55.2
Product energy	300	850	700	850	790	840	510	1010
Protein (crude)	.17	.1	.12	.45	.5	.42	.22	80
Protein (digest)	.123	.073	.11	.379	.466	.373	.193	60
Arginine	.007	.0048	.004	.047	.038	.014	.008	.035
Lysine	.008	.0032	.011	.0155	.032	.0063	.0037	.069
Methionine	.002	.0015	.002	.0041	.007	.0095	.003	.009
Meth. + cyst.	.0054	.0028	.0051	.0109	.0144	.0155	.006	.023
Tryptophane	.004	.0017	.002	.0046	.0076	.0021	.002	.011
Glycine	.009	.003	.007	.023	.027	.015	.008	.042
Fat	.025	.05	.005	.050	.005	.02	.015	.01
Fiber	.27	.06		.12	.03	.06	.11	.01
Calcium	.013	.0002	.009	.0015	.002	.001	.003	.0028
Phosphorus (tot.)	.0023	.005	.007	.0055	.0065	.004	.007	.0022
Phosphorus (avl.)	0	0	.007	0	0	0	0	.0022
Niacin	20	20	5	75	9.5	20	30	14
Riboflavin	5.5	.9	13	2.4	1.2	.7	1	.65
Pantothenic acid	13.5	3.4	21	24	6.0	4.5	5.8	.5
Choline	680	430	1160	760	1300	200	500	300
Vitamin A	.1	.001	0	0	0	.012	.002	0

Continued

Appendix table 2--Nutrient specifications of feedstuffs available in empirical test --Continued

Nutrient	Brewers yeast	Fishmeal, menhaden	Wheat middlings	Rice bran	Citrus pulp	Animal fat	Vitamin A	Dicalcium phosphate	Vitamin B-12
Net energy	66	72.8	50.5	59.5	70.5	0	0	0	0
Product energy	570	940	700	600	420	0	0	0	0
Protein (crude)	.45	.6	.155	.13	.06	0	0	0	0
Protein (digest.)	.414	.504	.128	.087	.03	0	0	0	0
Arginine	.022	.036	.008	.005	.0028	0	0	0	0
Lysine	.03	.048	.0075	.005	.002	0	0	0	0
Methionine	.007	.02	.0023	.0024	.0008	0	0	0	0
Meth. + cyst.	.012	.0295	.0059	.0034	.0019	0	0	0	0
Tryptophane	.005	.007	.0023	.001	.0006	0	0	0	0
Glycine	.017	.038	.009	.01	0	0.98	0	0	0
Fat	.01	.075	.04	.15	.02	0	0	0	0
Fiber	.03	.01	.07	.12	.135	0	0	0.24	0
Calcium	.001	.055	.0005	.0006	.019	0	0	.185	0
Phosphorus (total)	.014	.03	.008	.018	.001	0	0	.185	0
Phosphorus (avl.)	0	0	0	0	0	0	0	0	0
Niacin	200	25	40	130	9	0	0	0	0
Riboflavin	15	2.1	1.8	1.1	1	0	0	0	0
Pantothenic acid	50	3.8	10	.5	5.5	0	0	0	20
Choline	1,650	1,300	800	570	370	0	1.369	0	0
Vitamin A									

Appendix table 3 --Feedstuff price (dollars/ton) series used in empirical test

Feedstuff	1968			1969						
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
Corn	39.00	41.50	41.25	42.00	42.75	42.00	43 00	46.25	47.00	46.00
Tankage	96.50	98.00	95.00	95.00	97.50	90.00	87.50	92.50	93.50	102 50
Poultry byproduct	102.50	103 50	103.50	103.50	103.50	103.50	98.00	98.00	100.00	105.00
Feather meal 41	107.00	100.00	100.00	107.00	115.00	106.00	115.00	117.50	120.00	118.00
Cottonseed meal	73.40	58.40	74.40	77.40	77.40	69.90	69.40	67.40	67.40	71.90
Molasses cane	31.61	29.92	29.00	28.50	28.50	29.25	30.10	30.10	29.60	29.60
Urea	81.00	81 00	81.00	81.00	81.00	81.00	81.00	81.00	81.00	81.00
Alfalfa meal	39.60	42.60	46.60	49.20	50.80	50.80	49.80	48.60	42.60	41.60
Hominy, yellow	37.50	39.00	45.00	42.00	43.00	42.00	40.00	43.00	42.00	41.00
Whey	92.00	92.00	100.00	100.00	105.00	105.00	105.00	107.00	107.00	107.00
Peanut meal	94.00	100.00	100.00	100.00	100.00	100.00	96.00	96.00	96.00	83.80
Soybean *meal* 50	87.00	80.50	79 00	80.00	79.50	80.00	80.00	82.50	87.50	86.50
Corn gluten meal 41	86.00	78.00	76.00	76.00	76.00	74.00	72.00	70.00	66.00	76.00
Corn gluten feed	42.00	46.00	48.00	50.00	50 00	44.00	42.00	40.00	40.00	40.00
Blood meal	126.00	125.00	125.00	118.00	123.00	112.00	125.00	125.00	125.00	128.00
Yeast, brewers	126.80	126.80	126.80	126.80	126.80	126.80	126.80	126.80	126.80	126.80
Fishmeal (menhaden)	146.00	146.80	150.00	162.00	162.00	162.00	160.00	172.00	175.00	177.00
Wheat middlings	42.50	46.00	52.00	54.50	54.50	41.50	49.00	37.00	37.00	41.50
Rice bran	52.00	49.00	49.00	58.00	62.00	62.00	65.00	50.00	50.00	48.00
Citrus pulp	58.90	58.90	58.70	46.20	46.40	51.40	51.40	51.40	51.40	51.40
Animal fat	90.00	95.00	95.00	90.00	97.50	105.00	115.00	120.00	120.00	130.00
Salt	25.60	25.60	25.60	25.60	25.60	25.60	25.60	25.60	25.60	25.60
Vitamin A	850.00	850.00	850.00	850.00	850.00	850.00	850.00	850.00	850.00	850.00
Dicalcium phosphate	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
Vitamin B-12	431.00	431.00	431.00	431.00	431.00	431.00	431.00	431.00	431.00	431.00
Trace mineral mix	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000 00